ENVIRONMENT PROTECTION AUTHORITY

*EPA Guidelines*

# Environmental management of landfill facilities

## (municipal solid waste and commercial and industrial general waste)

January 2007

South Australia

**Erratum**

The following correction has been made to the table on page 28 of these guidelines in Table 3, 'Suggested measures for leachate containment and management systems':

For the measure 'Design and construct a leachate drainage layer at Class SB+, MB-, MB+ and L sites',

**'clean, hard, durable, sound gravel'**

replaces the third dot point, relating to the composition of the blanket drainage medium. The text 'clean, hard, durable, sound gravel, rock or aggregate' has been replaced.

EPA Guidelines for

# Environmental management of landfill facilities (municipal solid waste and commercial and industrial general waste)

**JANUARY 2007**

**EPA Guidelines for environmental management of landfill facilities (municipal solid waste and commercial and industrial general waste)**

*For further information please contact:*

Environment Protection Authority
GPO Box 2607
Adelaide SA 5001

Telephone: (08) 8204 2004
Facsimile: (08) 8124 4670
Freecall: 1800 623 445 (non-metro callers)

Email: *epainfo@epa.sa.gov.au*

Web site: <www.epa.sa.gov.au>

**ISBN 1 921125 34 9**

**January 2007**



*Printed on recycled paper*

# CONTENTS

## ACKNOWLEDGEMENTS

The assistance of the following organisations and individuals in developing this landfill guideline is gratefully acknowledged:

- all respondents who provided valuable feedback during the consultation process that informed the development of this guideline
- Waste Definitions Working Group (Waste Management Association of Australia/EPA and other agencies).
- Golder Associates
- Tonkin Consulting
- REM Resource and Environmental Management
- GHD Pty Ltd
- Anthony Lane, Lane Consulting
- Warnken ISE
- Jamie VanGulck, Assistant Professor Geoenvironmental Engineering, University of Manitoba, Canada

## ABBREVIATIONS

| | |
|---|---|
| AWWA | American Water Works Association |
| CQA | Construction Quality Assurance |
| EIS | Environmental Impact Statement |
| EPA | Environment Protection Authority (South Australia) |
| EPP | Environment Protection Policy |
| ISO | International Standards Organisation |
| LEMP | Landfill Environment Management Plan |
| LFG | Landfill Gas |
| MRRF | Materials Resource Recovery Facility |
| QA | Quality Assurance |

# 1 INTRODUCTION

Poor environmental practices have universally led to a degradation of the world's water, air and land resources. National and international environmental protection authorities are continually refining policies, regulation, practices and procedures with the aim of minimising the risk of environmental harm as part of transitioning to a sustainable future.

Landfill has an important role to play as part of the transition required to achieve sustainable resource recovery and waste management—the zero waste concept. The role for landfill primarily involves accepting those residual materials that are unable to be 'avoided, reduced, reused, recycled or recovered'. It is therefore vital that a precautionary approach be adopted to adequately address the environmental risks of landfill facilities.

Development and operation of landfill facilities in South Australia are activities of environmental significance and these activities must be carried out in accordance with the *Environment Protection Act 1993* (the EP Act). This guideline is intended to provide guidance to landfill operators, developers, planning authorities and regulatory bodies on the site selection, development, design, construction, operation, closure and post-closure management of municipal solid waste, and commercial and industrial (C&I) general waste landfill facilities so that they can comply with the EP Act.

## 1.1 Objectives

The principal objectives of this guideline are to:

- support initiatives by ZeroWaste SA and others to promote and encourage a focus on waste avoidance and minimisation rather than landfill disposal
- minimise the risk of adverse impacts on the water and air environments
- promote responsible land management and conservation
- promote responsible management of hazards and loss of amenity
- provide direction, certainty and consistency for the site selection, development, operation, closure and post-closure management of landfill facilities
- encourage rationalisation of the number of solid waste landfill facilities.

The key operational objectives are to:

- promote responsible landfill management
- fully utilise the available landfill space and compact the waste to minimise post-closure settlement
- minimise contamination of wastes that may constitute future resources
- minimise the generation and uncontrolled emissions of leachate and landfill gas that may impact on the environment
- improve procedures for monitoring, review and continuous improvement of site operations
- minimise the duration and requirement for post-closure maintenance and monitoring
- establish a mechanism for meeting guideline objectives if using variations and alternatives to suggested guideline measures.

## 1.2 Who should use this guideline?

This guideline applies to all new and existing solid waste landfill facilities that accept municipal solid waste and commercial and industrial general waste. (Definitions of these waste types are presented in Attachment 1).

Guidelines for solid inert waste and hazardous waste facilities are separate to this guideline. (Note: inert waste can be managed according to this guideline, but the design and operational requirements would be less than those specified in this guideline if it was disposed of as inert waste only. A separate guideline is being developed for inert waste.)

The actions that are required under this guideline for municipal solid waste and C&I general waste landfill facilities depend on three factors:

1. the life-cycle stage of the landfill, for example, new landfills or new developments on existing landfills, ongoing landfill, landfill closing before 1 July 2008 and landfill scheduled to close between 1 July 2008 and 1 July 2010
2. total landfill capacity, for example, small, medium or large
3. site conditions, including water flow, waste moisture content and leachate generation potential.

See Section 2 for more information on how to use this guideline, and in particular Section 2.1, which contains the schedule for guideline implementation.

## 1.3 How will EPA use this guideline?

The Environment Protection Authority (EPA) will use these guidelines as the basis for preparing comment or direction on development applications for proposed landfills under the *Development Act 1993*, and when making decisions under the Environment Protection Act relating to landfills, including when developing or varying conditions of licence under the Environment Protection Act.

### *Discretion in implementation of guidelines*

The guidelines recognise that existing and proposed landfill sites are each subject to a different suite of individual site-specific circumstances. The guidelines set an acceptable standard for the design, construction, operation and closure of landfill sites. However, inbuilt within the guidelines are mechanisms that provide for the consideration of individual site-specific circumstances. In applying the guidelines, the EPA will take into account the specific facts surrounding the proposed or existing landfill, and in particular:

- when determining how to apply the implementation timeframes, will have regard to an individual stakeholder's planning progress, planned and executed actions and associated justifications
- will have regard for local site conditions.

Use of the guidelines by the EPA will assist in maintaining consistent minimum environmental and landfill construction and operational standards, commensurate to the particular site circumstances.

## 1.4 Structure of this guideline

This guideline is structured into 16 sections that cover three broad areas (as shown in Figure 1). The early and later sections of the guideline are related to the document's structure. The middle sections of the guideline cover issues related to siting and management of landfill facilities, and present specific measures for the environmental management of these facilities.

Most of the middle sections follow the format of identifying relevant objectives of a particular aspect of landfill environmental management, specifying required outcomes that need to be achieved and then detailing suggested measures to meet required outcomes.

Following this introduction, Section 2: 'How to use this guideline' provides an overview of how the guideline, including its functional aspects, can be used to inform the environmental management of landfill facilities.

Section 3 details salient factors related to the screening and siting of landfill facilities, including community, planning regulations, buffer distances, water aspects, Aboriginal and heritage issues, flora and fauna, infrastructure, amenity and unstable areas. Section 4 then provides required outcomes and suggested measures for site layout for landfill facilities.

Suggested measures to address environmental assessment and water management strategies are presented in Section 5, in particular the landfill design considerations to manage potential impacts on groundwater and surface water environments. The specifics of designing leachate containment and collection systems for landfill facilities are addressed in Section 6: 'Leachate Containment and Management Systems', and include geotechnical aspects, site preparation, landfill liner system construction and leachate storage and treatment. Considerations and suggested measures for the use of geosynthetic materials in base liner systems, which may be used as an alternative or supplement to a compacted clay liner as part of an engineered barrier layer in a landfill base liner, are presented in Section 7.

From the management of liquid emissions the report moves onto management strategies for landfill gas and air quality in Section 8, with measures for managing landfill gas, dust and odour arising during landfill operation and post closure. Section 9 then goes on to provide suggested measures for capping systems, including the design and construction of an engineered barrier layer over the waste, in addition to a protective layer and growing medium. Considerations and suggested measures for the use of geosynthetic materials in capping systems are then examined in Section 10.

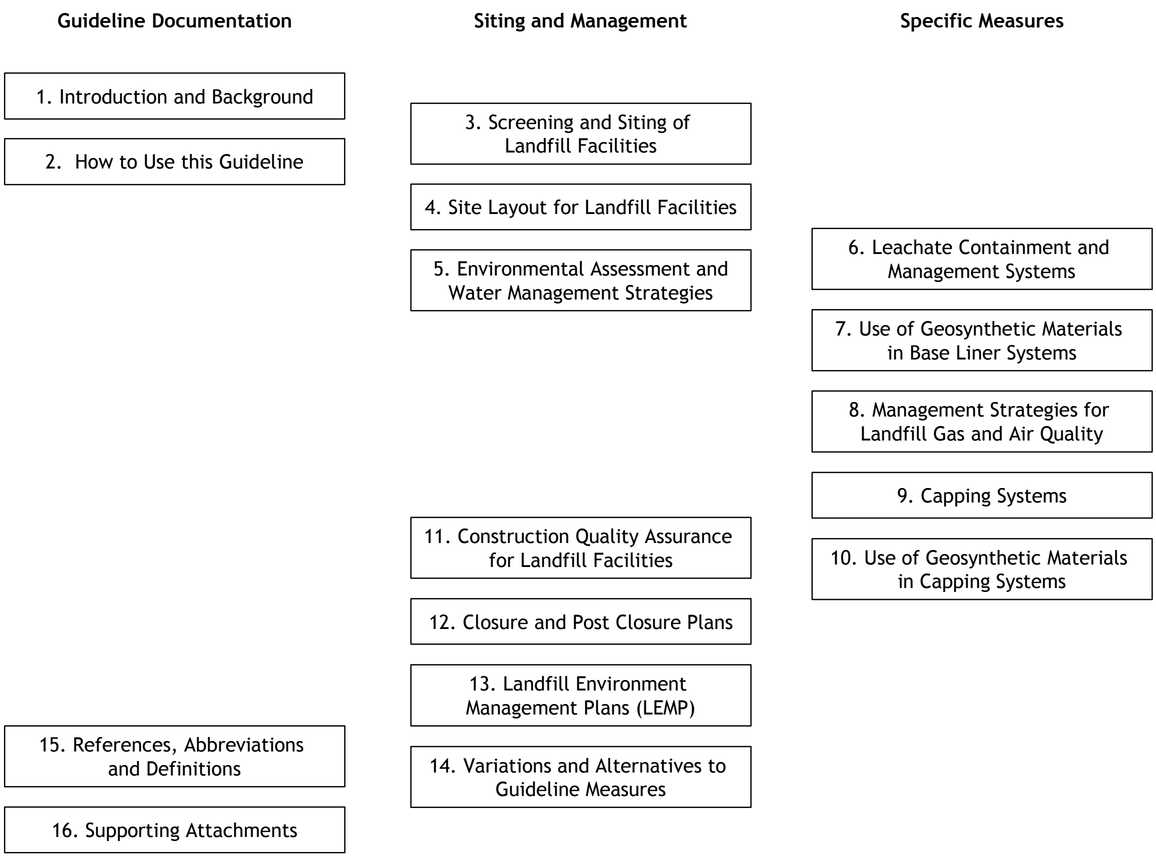



**Figure 1 – Structure of guideline**

Suggested measures for construction quality assurance for landfill facilities are the focus in Section 11, while the specifics of closure and post-closure plans are presented in Section 12. The requirements for landfill environment management plans (LEMP)', including general details, technical process and design, operational procedures, monitoring programs and reporting, and database systems are then examined in Section 13.

The measures (designs, techniques and methods) contained in this guideline reflect widely accepted practice. While this presents a reference design, variations may be permissible in some site-specific circumstances. Required steps are detailed in Section 14: 'Variations and alternatives to guideline measures'.

The guideline concludes with the References and Glossary (Section 15) and supporting attachments in Section 16.

## 1.5 Currency of this guideline

This guideline offers advice to assist with compliance with general environmental duties and specific environmental policies. It is subject to amendment and persons relying on the information should check with the EPA to ensure that it is current at any given time.

# 2 HOW TO USE THIS GUIDELINE

This guideline covers site selection, development, design, construction, operation, closure and post-closure management of landfill facilities that accept municipal solid waste, and commercial and industrial general waste. It is intended to provide guidance for how landfill operators can meet the environmental protection objectives of the regulatory framework. (It is a regulatory requirement that all landfill facilities in South Australia must comply with conditions of development approvals, EPA licence conditions and the *Environment Protection Act 1993.*)

The structure of this guideline is set up according to a framework of objectives, outcomes and suggested measures for each relevant aspect of environmental management for landfill facilities (see Figure 2). The objectives and required outcomes must be achieved for each element of the landfill facility and reflect the minimum requirements of policy and community expectations. The suggested measures represent acceptable standards for achieving objectives and required outcomes.

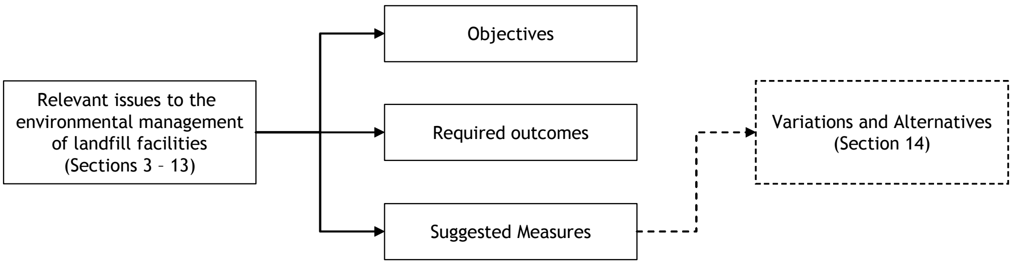



**Figure 2 – Guideline framework for addressing environmental management of landfill facilities**

Required outcomes and suggested measures to achieve these outcomes should be implemented in a manner that complements the attributes of the site's natural setting and its ability to control emissions such as leachate, litter and landfill gas. Engineering systems must be designed as a second line of defence (but not of lesser importance) to the natural attributes of the site to prevent adverse environmental impacts.

Suggested measures may not necessarily be appropriate for every landfill site. Where landfill facilities are located in particularly sensitive environments, alternative measures to those suggested may be required to achieve objectives and required outcomes. Therefore, merely following the measures does not absolve proponents from taking full responsibility and liability for their project and any off-site impacts.

Where proponents consider that alternative measures can achieve the objectives and required outcomes (equivalent performance), the alternatives must be supported by a site-specific risk assessment and a justification provided to the EPA. (See Section 14: 'Proposal of variations or development of alternatives to guideline measures').

All information presented in this guideline is likely to be applicable to landfill facilities throughout the entire life cycle of a landfill. However, there will be different levels of emphasis and relevance according to the particular life cycle stage of each landfill facility, ranging from project development and gaining regulatory approval, to closure and post-closure planning. As such, this guideline is not intended to be read sequentially. It is the responsibility of the landfill proponent to satisfy themselves as to their obligations under the guideline. The following sections are presented as a starting point for operators and proponents in using the guideline.

## 2.1 Guideline implementation schedule

The schedule for guideline implementation is based on specific life cycle stages, for example, closure pre 1 July 2008, closure between 1 July 2008 and 1 July 2010, continuing operation past 1 July 2010 and the development of new landfill facilities. Landfill operators and proponents should be aware of the following obligations and timelines:

- 2 January 2007
  - the guidelines apply to all new developments
- 1 July 2008
  - proponents either close landfills before, or by, 1 July 2008; or
  - proponents must have completed a closure plan (that has been accepted by the EPA) for implementation by no later than 1 July 2008;

  in either case, proponents would not need to implement the guidelines in full. However some aspects of the guidelines as applicable to some individual sites may apply.
- 1 July 2010:
  - all landfills must comply with the guidelines.

## 2.2 Requirements determined by landfill classification

Landfill facilities must be designed to minimise adverse impact on the environment. The landfill design will need to consider the environmental setting, the quantity and quality of waste to be disposed of, concerns of the host community, adjacent land use and economic and social factors.

Some of the suggested measures to achieve the objectives and required outcomes for landfill design vary subject to the EPA landfill classification. For example, the suggested measures for design of leachate containment, collection and management systems are illustrated in Table 3 of Section 6: 'Leachate containment and management systems', which vary according to landfill classification.

The EPA classifies landfill facilities based on:

- waste disposal rate and total landfill capacity (small, medium and large)
- site conditions influencing risks to protected environmental values of waters and the potential to generate leachate based on the risk of water flow into the waste, waste moisture content and climatic conditions (**Type B+** and **Type B-**).
- Note that large landfills have a set of requirements over and above small and medium landfills irrespective of the potential to generate leachate.

The three classes of landfill facilities based on the total landfill capacity are presented in Table 1 (small (**S**), medium (**M**) and large (**L**) facilities). These assume a minimum waste density (excluding daily cover) of 0.5 t/m3 for small landfills and 0.65 t/m3 for medium and large landfills. For the classification by size it is assumed that there are no existing or proposed landfills within 3 km of the site being classified. The site classification must consider all waste placed in landfills at the site and within 3 km of the site.

**Table 1 Landfill class based on total capacity**

| Landfill type | Small (S) | Medium (M) | Large (L) |
|---|---|---|---|
| Total landfill waste capacity: | | | |
| (tonnes) | <26 000 | >26 000 and <130 000 | >130 000 |
| ($m^3$) | <52 000 | >52 000 and <200 000 | >200 000 |
| Comment | Proponents of small facilities must demonstrate that it is not practical to participate in a regional waste management plan | | |

Anticipated waste disposal rates can be calculated on the basis of designed operational life for a landfill. For example, a small (S) landfill with a 20 year operation would receive less than 1300 tonnes of waste per annum.

Figure 3 presents a flow chart as a screening tool to assess the landfill type based on site conditions (Type **B+** and **B-)** for small and medium landfill facilities. (There is no distinction between landfill types based on site conditions for large landfill facilities (Class L). Because of their size, large landfills have additional requirements over and above small and medium sized landfills, regardless of the site potential to generate landfill.)

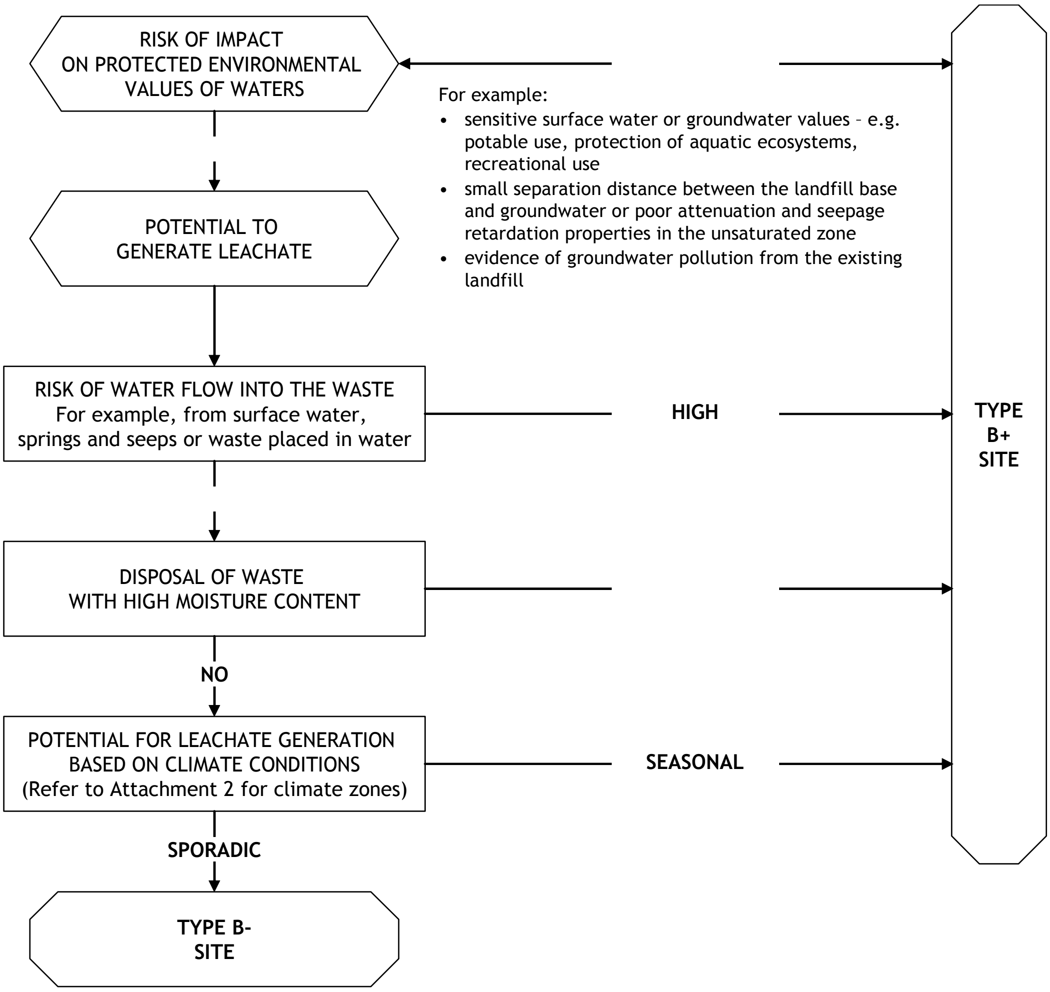



**Figure 3 - Flowchart to assess the landfill class based on site conditions**

In merging the classification based on capacity with the classification based on site-specific conditions, a landfill site is classified as either **Class SB-, SB+, MB-, MB+ or L.** A description of these site classifications is presented in Table 2, and example site classifications for landfill facilities are given in Attachment 1.

**Table 2 Landfill classification based on capacity and site-specific conditions**

| Classification | Description |
|---|---|
| **SB-** | Small landfill with a total waste capacity of less than 26 000 tonnes (approximately 52 000 cubic metres) and with low potential to generate leachate, low risk of water flow into the waste, no disposal of waste with high moisture content and sporadic potential for leachate generation based on climatic conditions (as defined by location on the potential leachate generation map in Attachment 2). |
| **SB+** | Small landfill with a total waste capacity of less than 26 000 tonnes (approximately 52 000 cubic metres) and with either high potential to generate leachate, and/or high risk of water flow into the waste, and/or disposal of waste with high moisture content and/or seasonal potential for leachate generation based on climatic conditions (as defined by location on the potential leachate generation map in Attachment 2). |
| **MB-** | Medium landfill with a total waste capacity between 26 000 tonnes (approximately 52 000 cubic metres) and 130 000 tonnes (approximately 200 000 cubic metres) and with low potential to generate leachate, low risk of water flow into the waste, no disposal of waste with high moisture content and sporadic potential for leachate generation based on climatic conditions (as defined by location on the potential leachate generation map in Attachment 2). |
| **MB+** | Medium landfill with a total waste capacity between 26 000 tonnes (approximately 52 000 cubic metres) and 130 000 tonnes (approximately 200 000 cubic metres) and with either high potential to generate leachate, and/or high risk of water flow into the waste, and/or disposal of waste with high moisture content and/or seasonal potential for leachate generation based on climatic conditions (as defined by location on the potential leachate generation map in Attachment 2). |
| **L** | Large landfill with a total waste capacity of greater than 130 000 tonnes (approximately 200 000 cubic metres). Large landfills have increased environmental management requirements by virtue of their size. These requirements exist independent of a site's potential for leachate generation. |

## 2.3 What sections relate to specific landfill life cycle stages?

There are three broad stages in the life cycle of a landfill. These stages include:

- project development and gaining regulatory approval, with a focus on landfill design, screening and siting, and site layout
- day-to-day operations
- closure and post-closure planning and management.

Additional to these stages is an ongoing requirement for community consultation throughout the entire life cycle of the landfill.

Further information on specific activities within these stages, in addition to the location of relevant objectives, outcomes and suggested measures within this guideline, is presented in Section 2.3.1. (Note that many activities cross over more than one stage, such as landfill environmental management plans).

### 2.3.1 Project development and regulatory approval

The typical process for project development is presented below (stages where regulatory approval is required are shown in italics and reference is also made to relevant sections of this guideline):

- development of a waste management plan that is assessed against the State Waste Strategy and the Regional Waste Management Plan as well as industry-specific waste management plans and strategies (where applicable)
- screening and siting assessment (including risk assessment and concept design of management strategies—see Section 3: 'Screening and siting of landfill facilities')
- *development application* through local government and the Development Assessment Commission. (Note: this is not a guideline to apply for major developments: major developments have a separate process that must be followed. Further information can be found in the *Development Act 1993*)
- landfill environment management plan (LEMP) including
  - detailed design (Section 4)
  - construction quality assurance (CQA) plan (Section 11)
  - landfill operation, monitoring and corrective actions (Section 13)
  - management review and *annual report to the EPA*
  - closure plan (Section 12)
  - closure and post-closure maintenance, and *monitoring* and *annual report to the EPA*

  (Note that more guidance on LEMPs is provided in Section 13 of this guideline)
- construction phase, including
  - documentation of CQA
  - as-built details in *As Constructed Report*
- *application and issue of an environmental authorisation(licence) for operation.*

The EPA must be notified by the developer or licensee if there are changes to site conditions compared with those documented and approved. Similarly, EPA notification in advance is required for proposed changes to agreements between the EPA and the project stakeholders during all stages of site development, operation, closure and post-closure.

Changes may require a new *development application* to be made to the relevant authority.

The developer or landfill operator must define clear roles, responsibilities and communication lines for personnel and organisations that are commissioned for each element of the landfill development, construction and operation. This must include the role, responsibilities and communication lines for the responsible person or organisation for contact with the EPA.

The proponent needs to provide information within appropriate timeframes and within identified consultation periods. This must allow time for both the planning authority and the EPA to review submissions and respond to information if design changes are suggested.

*Landfill design*

Guidance on environmental management issues relating specifically to landfill design are presented in the following sections:

- Section 4: 'Site layout for landfill facilities'
- Section 5: 'Environmental assessment and water management strategies for landfill design'
- Section 6: 'Leachate containment and management systems'
- Section 8: 'Management strategies for landfill gas and air quality'
- Section 11: 'Construction quality assurance for landfill facilities'.

*Screening and siting for potential landfill facilities*

The location of a landfill is the primary determinant of the extent to which the landfill will pose an environmental risk.

Guidance for screening and siting for potential landfill facilities is presented in Section 3: 'Screening and siting of landfill facilities'.

### 2.3.2 Day-to-day operations

A landfill environment management plan (LEMP) forms a significant component in determining required day-to-day operations to meet environmental management obligations of landfill facilites. LEMPs must be prepared by proponents and licensees to ensure that commitments in any environmental impact statement (EIS), development application, conditions of planning consent and licence conditions are fully implemented.

The LEMP provides the basis for management and mitigation of environmental impacts during construction, operation and closure of the landfill, as well as the post-closure period.

Guidance for the requirements of these plans is presented in Section 13: 'Landfill environment management plans (LEMP)'.

### 2.3.3 Landfill closure and post-closure period

Landfills are to be closed in accordance with an approved closure plan to ensure the long-term protection of human health and the environment and to minimise the duration of post-closure maintenance.

Guidance for this task is presented in Section 12: 'Closure and post-closure plans'.

### 2.3.4 Community issues

Landfill planning, design, operation and closure will need to take into account the concerns of the host community. Community consultation is thus a vital component of all stages in the life cycle of a landfill.

Guidance for considering the concerns of the host community is presented in the *Guidelines for community consultation for waste management and recycling facilities (EPA 2003).*

## 2.4 Additional information

South Australian legislation is available free of charge on the internet from <www.parliament.sa.gov.au/dbsearch/legsearch.htm>. All other relevant legislation is available from the Australasian Legal Information Institute at <www.austlii.edu.au>.

Copies of legislation are available for purchase from:

| | | |
|---|---|---|
| Government Information Office<br>Lands Titles Office, 101 Grenfell Street<br>Adelaide | Telephone:<br>Internet: | 13 23 24<br><shop.service.sa.gov.au> |

Guidelines and other publications are available from the publications section of the EPA website <www.epa.sa.gov.au/pub.html>, by e-mail epainfo@epa.sa.gov.au or by telephone (08) 8204 2004 (Freecall 1800 623 445 for country callers).

| | | |
|---|---|---|
| *For general information please contact:* | Telephone: | (08) 8204 2004 |
| Environment Protection Authority<br>GPO Box 2607<br>Adelaide SA 5001<br>E-mail: epainfo@epa.sa.gov.au | Facsimile:<br>Freecall (country):<br>Internet: | (08) 8124 4670<br>1800 623 445<br><www.epa.sa.gov.au> |

Australian Standards are available for purchase online at <www.standards.com.au>, by e-mail: <sales@standards.com.au>, by telephone: 1300 654 646 or by post: GPO Box 5420, Sydney, NSW 2001, Australia.

# 3 SCREENING AND SITING OF LANDFILL FACILITIES

The location of a landfill and the types of waste it is to receive are the primary determinant of the extent to which the landfill will pose an environmental risk. The aim of choosing a suitable site is to avoid the need to take action to reduce environmental impacts where natural features already protect environmental quality and minimise the risk to the environment. In an ideal situation, these barriers would be the primary mechanism used to protect the environment and avoid nuisance to the host community. Engineering and management measures will be considered as a secondary measure to prevent the potential for adverse impact to human health, the environment and amenity.

This section deals with siting issues and presents the objectives and considerations for the assessment and screening of landfill facilities for proponents and regulatory bodies.

## 3.1 Objective

The objective of screening and siting of landfill facilities is to:

- assess the relative suitability of potential sites based on consideration of capacity, potential risks to the environment, natural resources, transport access, infrastructure and social and economic factors
- identify sites that are not suitable because of unacceptable risks to the environment or other factors.

## 3.2 Waste management plan

Siting and screening of municipal solid waste and commercial and industrial (C&I) general waste landfill facilities should consider aspects of the regional waste management plan. This includes the waste hierarchy, waste minimisation initiatives, recycling and resource recovery infrastructure, waste generation rates, capacity of the landfill facility and collection and pre-treatment strategies.

## 3.3 Community issues

Assessment of potential landfill sites will need to consider the concerns of the host community. This will allow information sharing and early identification of issues of interest that can be considered in the screening process. A program of community participation can also be continued for subsequent phases of the project.

Guidance for considering the concerns of the host community is presented in the *Guidelines for community consultation for waste management and recycling facilities* (EPA March 2003).

## 3.4 Planning regulations

Consideration needs to be given to planning issues including site access, land zoning and acceptable land uses for selected sites and adjacent areas.

## 3.5 Environmental considerations

Screening and assessment of the suitability and relative merits of potential landfill sites will require a preliminary assessment of site conditions and potential impacts on the environment. This includes consideration of topography, surface water, drainage, hydrogeology (groundwater), geology, climate (including air quality and odour modelling) and flora and fauna. Further details of some of these items are presented below. Assessment of site conditions typically includes a review of available information and a program of site investigation.

## 3.6 Buffer distances

Buffer distances provide separation between the landfill and sensitive land uses and act as a primary control of potential adverse impacts. Appropriate site management practices during site development, the operational stage and for closed landfills will also be required to protect sensitive land uses.

The buffer distance between the waste operations area and sensitive land uses should be incorporated into the licensed area to prevent future encroachment of incompatible activities and land uses. The buffer distance would need to be maintained for a specified post-closure period, which will be at least 25 years. The operator may not necessarily need to own the land comprising the buffer zone, but would need to negotiate an agreement to avoid encroachment by incompatible land uses.

Waste management facilities should be appropriately separated from sensitive land uses and environmentally sensitive areas. The separation distance (buffer) between the waste operations area and sensitive uses should be incorporated within the allotment (premises) containing the waste management facility. The waste operations area (or landfill facility) includes all closed, operating and futures cells. The relationship of the buffer zone to the waste operations area is shown in Figure 4.

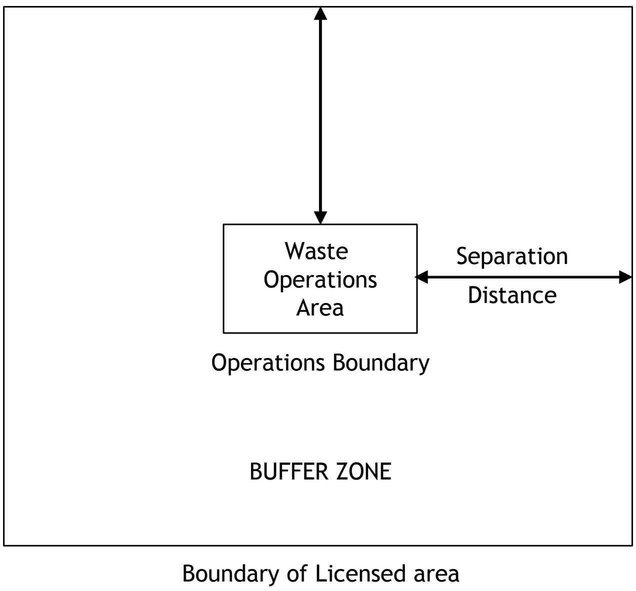



**Figure 4 – Relationship of buffer zone to the waste operations area (landfill facility) (Source:** *Guidelines for separation distances***—EPA August 2000)**

The buffer area may be suitable for planting of vegetation as a visual screen and to assist in control of litter, dust and odour.

The following minimum buffer distances shall be maintained at municipal solid waste and C&I general waste landfill facilities:

- 500 m to residential development, rural townships and highways or arterial road networks. A lesser buffer may be acceptable where it is considered compatible with the surrounding area and land uses so that there will be an effective buffer of 500 m between the landfill and any sensitive or incompatible land use.
- 3000 m between an airport utilised by turbojet aircraft and 1500 m between an airport utilising piston aircraft respectively, and a landfill that attracts birds (due to food or other wastes). Landfills that abut this buffer zone will need to demonstrate compliance with the requirements of the Civil Aviation Authority and as approved by the EPA.

Buffer distances to surface water and the 100 year flood plain are presented in Section 3.8. Greater separation distances may be required based on site-specific conditions.

Where these buffer distances are not available, management practices for landfill design and operation have to be developed to ensure a similar level of protection for sensitive land uses. See Section 14 for more information on this equivalency of performance (variations or alternative approaches).

## 3.7 Water

The principal object of the *Environment Protection (Water Quality) Policy 2015* is to achieve the sustainable management of waters, by protecting or enhancing water quality while allowing economic and social development.

An assessment of the surface water and groundwater conditions and appropriate management of impacts at potential landfill sites must be made by a qualified and experienced person so that the protected environmental values of the waters are safeguarded.

## 3.8 Surface water

Landfills are generally not permitted in sensitive water catchment areas or near marine or coastal reserves. If a new site is required in one of these areas or an old site already exists, they will require significant engineering and management controls to protect the environmental values of water.

A minimum buffer distance of 500 m shall be maintained between areas dedicated for waste disposal and the nearest surface water (whether permanent or intermittent) and the '100 year flood plain'.

Greater separation distances or increased management controls may be required based on assessment of surface water conditions at the site(s) and the potential consequences of uncontrolled discharges to surface waters.

## 3.9 Groundwater

Landfill facilities are not encouraged in areas of karstic terrain, areas where waste is proposed to be placed below the groundwater table, areas with groundwater springs or seeps, areas of sensitive groundwater values (for aquatic ecosystems or potable use) or groundwater protection zones. Sites in these areas would require significant engineering and management controls to protect the environmental values of waters.

Landfills are not encouraged where the interface between the engineered landfill liner and natural soils is within:

- 15 m of unconfined aquifers bearing groundwater with < 3000 mg/L total dissolved salts
- 5 m of groundwater with a water quality of between 3000 and 12 000 mg/L total dissolved salts
- 2 m of groundwater with a water quality of over 12 000 mg/L total dissolved salts.

These separation distances apply to the seasonal high water table at the site. Greater separation distances may be required by the EPA based on site-specific conditions and the risk of impact on the protected environmental values of groundwater.

The proponent can apply to the EPA for an exemption from Clause 13 of the *Environment Protection (Water Quality) Policy 2015* (Water EPP) in form of an attenuation zone.

If an exemption is granted the licensee is required to comply with the Water EPP at the agreed compliance point or at the site boundary (boundary of the premises), whatever is agreed upon. Compliance criteria are determined by the native groundwater quality or water quality criteria as set out in Schedule 2 of the Water EPP, whatever is the greater.

If an attenuation zone cannot be granted, the EPA will determine the point of compliance based on a site-specific assessment.

Preferred sites for landfill facilities are those that reduce the risk of impact on the environmental values of groundwater by providing a natural unsaturated attenuation zone beneath the base liner for contaminants that may infiltrate through the liner. Natural unsaturated zones that retard flow of water that infiltrates through the liner are also preferred. For example, sites with clay soils that have low permeability and natural attenuation properties are preferred to those with sandy soils.

## 3.10 Aboriginal and heritage issues

Landfill screening and siting must consider the effect on any Aboriginal sites of archaeological, anthropological or other significance, including any sites listed in the Register of the National Estate and the SA Register of Aboriginal Sites and Objects, or identified after consultation with Aboriginal councils or groups.

## 3.11 Flora and fauna

Landfills are not be permitted:

- in areas with critical habitats of taxa and communities of flora and fauna listed under the *Flora and Fauna Guarantee Act 1988*
- where they have a potential significant impact on threatened species and ecological communities as identified in the *Environmental Protection and Biodiversity Conservation Act 1999*, except with the approval of the Commonwealth Environment Minister
- in other protected areas for flora and fauna listed in state and federal regulations.

Screening and siting of facilities and management strategies should consider potential impacts on flora and fauna from clearing of vegetation, modification of surface water conditions or other aspects of landfill development. Potential impacts include loss of habitat, displacement of fauna, loss of biodiversity, spread of plant diseases and weeds, litter, creation of new habitats for scavenger or predatory species, or erosion.

## 3.12 Infrastructure

Infrastructure will need to sustain landfill activities. Screening and siting will need to consider the following:

- the capacity and safety of access roads for the anticipated vehicle traffic
- water supply for fire fighting, potable use and other site purposes
- power and sewerage disposal facilities.

## 3.13 Amenity

Consideration should be given to potential impacts on amenity for affected parties surrounding the site including vehicle traffic on the access road to the site, visual aspects, odour, litter and dust.

## 3.14 Unstable areas

Landfills must not be located in areas that are susceptible to ground movements that may adversely impact on the integrity of the landfill and engineering systems such as the liners, leachate collection system, landfill gas collection system and final cover.

Consideration must be given to existing conditions or potential changes to site conditions from progressive landfill development that may impact on stability, including topography, surcharge loads, drainage and surface water.

Potential unstable areas include areas that are susceptible to undergo ground movements due to the following:

- landslides or other ground movements associated with slopes
- seismic (earthquake) events that cause displacement at fault lines or in zones of liquefaction
- excessive differential or total settlement from uncontrolled fill, collapse of low density soils or consolidation of compressible soils
- collapse of voids or settlement of low strength zones associated with karstic terrain or former mining operations.

# 4 SITE LAYOUT FOR LANDFILL FACILITIES

Careful planning of the site development and layout is important to facilitate waste diversion and recycling, coordinate site activities, manage health and safety and minimise potential impacts on amenity and the environment.

## 4.1 Objectives

The objectives of planning the site layout and progressive development are to:

- minimise environmental impacts
- minimise health and safety risks for site personnel and the general public
- maximise waste diversion and recycling
- coordinate site activities and make efficient use of on-site resources
- manage potential impacts on local amenity.

## 4.2 Required outcomes

The required outcomes of the site layout and progressive development include:

- Plan the site access for efficient site operation, to protect local amenity and to prevent unauthorised access to the site and the active tipping face.
- Facilitate waste diversion and recycling, and minimise public access to the active tipping face.
- Locate site facilities to minimise the risks posed by landfill gas, subsidence and other potential hazards from the landfilled waste.
- Plan the layout of excavations, stockpiles, waste disposal cells and cell filling sequence, in order to optimise site operations, to minimise the potential for leachate generation and to manage surface water. It must also facilitate landfill closure, minimise post-closure monitoring and maintenance and manage litter and other potential hazards and impacts on local amenity.
- Maintain geotechnical stability of excavations, stockpiles, the waste, final cover and surrounding areas. This relates to the development of each stage or cell of the landfill, and to overall site stability.
- Plan the facilities and site layout to allow a prompt and efficient emergency response to fire outbreaks.
- Minimise the impact on visual amenity.

## 4.3 Suggested measures

The following measures are suggested for achieving the objectives and required outcomes for the site layout:

- Incorporate screening, mounding and landscaping to protect local amenity and manage drainage of surface water. This may need to occur in stages.
- Operate the landfill as a series of cells that minimise the size of the active tipping face, facilitate covering and compaction of the waste, maintain geotechnical stability and take less than two years to fill.

- Limit the extent of the active tipping face to the minimum practicable for waste placement, compaction and placement of daily cover.
- Progressively rehabilitate completed cells by placement of final cover and implementation of landfill gas management measures.
- Control site access with perimeter fencing and lockable gates.
- Install and operate a gatehouse at the site entrance to control site access, to record and vet the incoming waste and to facilitate payment of waste disposal fees. The gatehouse may incorporate a weighbridge subject to the annual quantity of waste disposed at the facility.
- For facilities with public access or waste pre-processing, provide a waste transfer station with recycling and drop off areas to encourage waste sorting and to control access to the active tipping face.
- Locate site facilities in consideration of site access roads and the availability of water, power and other services.
- Consider the local wind conditions when planning cell layout, screening mounds and litter management.

# 5 ENVIRONMENTAL ASSESSMENT AND WATER MANAGEMENT STRATEGIES FOR LANDFILL DESIGN

An environmental assessment of the site is required so that the landfill can be designed to minimise adverse impact on the environment. This section focuses on landfill design to manage potential impacts on the groundwater and surface water environments.

Additional environmental considerations associated with landfill facilities for surface water, groundwater, flora and fauna, landfill gas, air quality and noise are included in the following sections:

- Section 3: 'Screening and siting of landfill facilities'
- Section 8: 'Management strategies for landfill gas and air quality for landfill design'
- Section 13: 'Landfill environment management plans'.

## 5.1 Objective

The objective of environmental assessment is to gain a comprehensive understanding of the environment where the landfill is located, so that water management strategies can then be designed to safeguard the protected environmental values of surface water and groundwater in accordance with the Environment Protection (Water Quality) Policy.

## 5.2 Required outcomes

The required outcomes include:

- assessment of the hydrogeological (groundwater) conditions in the area of the landfill (including the landfill and the surrounding area)
- assessment of surface water and drainage conditions
- assessment of climatic conditions
- development of water management strategies to safeguard the protected environmental values of surface water and groundwater.

## 5.3 Suggested measures

### 5.3.1 Assessment of site conditions

Assessment of site conditions typically includes a review of relevant published and other available information and conducting a program of site investigation.

### 5.3.2 Hydrogeological setting

A conceptual hydrogeological model should be prepared and the assessment of the hydrogeological setting should include the following aspects:

- local and regional geology
- distribution and physical properties of aquifers
- groundwater conditions in each aquifer including confinement, groundwater depth, groundwater flow direction and rate, aquifer thickness, saturated thickness, hydraulic conductivity, porosity and hydraulic gradient
- groundwater interaction with surface water
- groundwater quality and protected environmental values
- groundwater users in the surrounding area and other sensitive receptors
- contaminant attenuation properties of the natural subsurface conditions.

The site investigation typically includes a program of site inspection, borehole drilling, test pit excavation, sampling and logging of subsurface materials, groundwater well installation, testing of aquifer characteristics and groundwater sampling and testing. The number and construction details of wells should consider the size of the landfill, the risk of contamination and the hydrogeological setting. As a minimum, one well should be located up hydraulic gradient of the landfill and two wells located down hydraulic gradient. The location of groundwater wells should take into account ongoing utilisation as monitoring wells during landfill operation and for post-closure monitoring.

The Department of Water, Land and Biodiversity Conservation have guidelines, regulations and a permit system for installation of groundwater monitoring wells.

For more detailed information refer to the *DRAFT Guidelines—Groundwater investigation, assessment and monitoring for landfill for landfills for municipal solid waste and commercial and industrial general waste (to be published in 2007).*

### 5.3.3 Climatic conditions

Assessment of climatic conditions includes rainfall, evaporation and wind conditions.

### 5.3.4 Surface water and drainage conditions

Assessment of surface water and drainage conditions includes topography, drainage, vegetative cover, flow, water quality, protected environmental values and users.

## 5.4 Assessment of potential impacts and management strategies

### 5.4.1 Water management strategies

Development of water management strategies will need to consider the following:

- site conditions
- water requirements for site operations including fire fighting, dust control and irrigation and construction of landfill cells and capping
- separation of stormwater and leachate
- safeguarding the protected environmental values of surface water and groundwater from potential impacts associated with contaminated stormwater, sediment and leachate.

Leachate is water that comes into contact with the waste and is potentially contaminated by nutrients, metals, salts and other constituents.

Groundwater and surface water can be contaminated by untreated leachate from landfill sites. Leachate has the potential to cause serious water pollution if not managed properly. Surface water may also be adversely affected by sediment or contaminants in uncontrolled stormwater flows.

Water quality objectives and limitations on water discharge to land, surface waters and groundwater to safeguard the protected environmental values of these waters are presented in the *Environment Protection (Water Quality) Policy*. The purpose of this policy is to achieve the sustainable management of waters by protecting and enhancing water quality while allowing economic and social development.

### 5.4.2 Stormwater management

Stormwater management strategies must consider the following:

- management of surface water on site and control and monitoring of off-site stormwater discharge
- diversion of stormwater away from areas containing waste using drainage features and bunds
- erosion and sediment control along drainage lines, disturbed areas and soil stockpiles. This includes stormwater flow control, vegetation, detention ponds, minimising land disturbance and other temporary and permanent erosion protection measures.

Management strategies and design criteria for storm events should consider potential receptors and the consequences of uncontrolled discharge. Typical design criteria include the 1 in 10 year or 1 in 20 year recurrence interval storm event for design of drainage features and the 1 in 100 year recurrence interval storm event to assess the risk of major breakdown events such as failure of detention ponds, or flooding of the waste area or sensitive facilities or receptors.

Detention ponds should incorporate erosion and flow control measures including erosion resistant banks, baffles and spillways.

Guidance on stormwater management is presented in *Stormwater pollution prevention code of practice for the building and construction industry* (EPA 1999) and *Stormwater pollution prevention code of practice for local, state and federal government* (EPA 1997).

(Note that stormwater management is also an issue for closure and post-closure planning and management and is further discussed in Section 12.3.6).

### 5.4.3 Leachate management

Strategies to manage leachate will need to consider the following:

- potential generation and composition of leachate during operation of active cells and after closure of landfill cells
- limiting infiltration through the final cover to a rate less than the infiltration through the landfill base. This will minimise the risk of a build-up of leachate in the waste and associated problems with saturation of the waste, leachate collection and treatment or breakout seepage through the landfill surface
- design and operation of a leachate containment and collection system in the landfill cells
- safeguarding the protected environmental values of surface water and groundwater
- potential offensive odours
- health and safety and minimising human contact with the leachate.

Figure 3 in Section 2 presents a flowchart as a screening tool to assess the potential to generate leachate based on the risk of water flow into the waste, waste moisture content and climatic conditions. This is linked to the landfill classification system, as well as suggested measures for leachate containment, collection and management systems in Section 6: 'Leachate containment and management systems'.

Further assessment of the potential to generate leachate may be required based on site factors. These factors may include, but not be limited to, the risk of impact on the protected environmental values of waters or uncertainty in the screening process presented in Figure 3 of Section 2. For example, sites that are near the boundary of the leachate generation regions shown in Attachment 2 may require further assessment. Further assessment could be carried out by inspection of site records from leachate monitoring and water balance modelling, especially near the boundary of regions shown in Attachment 2.

Detailed water balance modelling considers precipitation, surface evapotranspiration, surface runoff, water storage in the soils and waste, leachate collection and infiltration through the landfill base. The modelling considers climatic conditions, landfill geometry, waste composition, the leachate collection system, final cover and surface vegetation. Water balance modelling to compare different options for leachate containment or final cover systems can be carried out using proprietary software such as the USEPA Hydrologic Evaluation of Landfill Performance (HELP), LandSim or other acceptable models. Water balance modelling will need to consider uncertainties and limitations involved with the input data and the model. Modelling results should be compared to site records from leachate monitoring.

Assessment of the potential impact of leachate on groundwater needs to take into account the potential infiltration of leachate through the landfill base and the interaction with groundwater (based on the above assessment of the hydrogeological setting). The assessment will need to take into consideration the potential concentration and mobility of contaminants in the leachate and safeguarding the protected environmental values of groundwater and surface water. At operating facilities, the assessment should also take into account the results of the leachate monitoring and groundwater monitoring programs.

Consideration should be given to cases during operation of active cells and after closure of landfill cells.

Guidance for design of leachate containment, collection and treatment systems as part of a water management strategy is presented in Section 6: 'Leachate containment and management systems'.

Guidance on design of final cover for landfill closure is presented in Section 12: 'Closure and post-closure plans'.

# 6 LEACHATE CONTAINMENT AND MANAGEMENT SYSTEMS

Leachate is water that comes into contact with waste and is potentially contaminated by nutrients, metals, salts and other constituents. Groundwater and surface water can be contaminated by untreated leachate from landfill sites. Leachate has the potential to cause serious water pollution if not managed properly. Surface water may also be adversely affected by sediment or contaminants in uncontrolled stormwater flows.

## 6.1 Objectives

The objectives of leachate management are to:

- minimise the generation of leachate
- manage leachate to safeguard the protected environmental values of surface water and groundwater
- detect and promptly remediate pollution of surface water or groundwater.

## 6.2 Required outcomes

The required outcomes include:

- plan the landfill development and surface water management systems to minimise the generation of leachate
- design and construct a leachate collection and management system to safeguard the protected environmental values of groundwater or surface water
- implement a system that can be maintained and will continue to meet the objectives and required outcomes.

## 6.3 Suggested measures

Suggested measures to achieve the objectives and required outcomes are presented in Table 3. Some measures are subject to the landfill classification, which is based on the waste stream and the site conditions. The method to assess the site classification is presented in Section 2.2.

The suggested cross-section profile for leachate containment and collection systems for each site classification is summarised in Table 4.

Guidance on assessment of the environmental setting and water management strategies to safeguard the protected environmental values of surface water and groundwater are presented in Section 5: 'Environmental assessment and water management strategies for landfill design'.

Guidance on planning the site layout to minimise leachate generation is presented in Section 4: 'Site layout for landfill facilities'. This includes suggested measures relating to operation of the landfill in cells and a limit to the cell size and duration.

**Table 3 Suggested measures for leachate containment and management systems**

| Suggested measure | Considerations and details |
|---|---|
| **Investigation** of geotechnical aspects for design and construction of the leachate collection system. | Considerations include subgrade conditions at the cell base, geotechnical slope stability, groundwater conditions, excavation conditions and potential earthworks construction materials.<br><br>Slope stability considerations include temporary and permanent slopes, interface strength parameters of lining systems and global landfill stability.<br><br>Earthworks construction materials include potential materials for a clay liner, drainage layer and other fill, as appropriate. Further considerations and details for assessment of clay liner materials are presented in Attachment 3. |
| **Elevation of the base** of the liner at the leachate sump above groundwater. | Minimum distances of the interface between the engineered landfill liner and the natural soils above groundwater is presented in Section 3, 'Screening and siting of landfill facilities'. |
| **Site preparation** to provide a sound and stable subgrade and to promote surface drainage.<br><br>The prepared subgrade forms a surface for drainage and waste placement for Class SB- sites.<br><br>The prepared subgrade provides a sound and stable base for construction of the liner and leachate collection system for Class SB+, MB-, MB+ and L sites. | The subgrade for Class SB- sites must have a smooth surface and a minimum grade of 2% to the leachate sump.<br><br>The subgrade for other sites should promote runoff of surface water during construction and may be shaped similarly to the final surface of the liner, subject to subgrade conditions.<br><br>Compact the subgrade to a minimum dry density ratio of 95% relative to standard compaction (AS 1289 5.1.1) to a minimum depth of 0.150m.<br><br>Proof roll the prepared subgrade to assess the presence of zones that may require subgrade improvement.<br><br>Subgrade improvement is required in the following areas:<br>• where there is a risk of differential settlement that may adversely impact on the integrity or long-term performance of the leachate collection system<br>• to provide a sound platform for subsequent liner construction.<br><br>Subgrade improvement may be required in soils susceptible to collapse settlement, uncontrolled fill, voids or weak or compressible materials.<br><br>Subgrade improvement works should follow sound engineering principles and be carried out in accordance with a construction quality assurance plan. |
| Design and construct a **landfill liner system** for Class SB+, MB-, MB+ and L sites.<br><br>This is to promote collection of leachate, retard infiltration of leachate and manage escape of leachate from the landfill cell to levels that safeguard the protected environmental values of groundwater or surface water.<br><br>Other functions of the liner include attenuation of contaminants in | The liner system must be placed on the base and sides of the landfill or its component cells.<br><br>Utilise materials that are resistant to physical or chemical degradation by leachate. Calcareous materials may not be appropriate.<br><br>If a clay liner is used, it must:<br>• comprise a minimum thickness of 0.6 m for Class SB+ and MB- sites and 1 m for Class MB+ and L sites<br>• comprise a hydraulic conductivity of less than $1 \times 10^{-9}$ m/s<br>• undergo construction by uniform moisture conditioning and uniform compaction using a sheepsfoot roller (AS 3798-1996) in layers with a maximum compacted thickness of 200 mm. There must be effective bonding between successive layers that includes kneading between layers and scarification and moisture conditioning between successive layers. The maximum layer thickness and number of layers is intended to promote uniformity within each layer and reduce the probability that preferential |

| Suggested measure | Considerations and details |
|---|---|
| leachate seeping through the liner and retardation of lateral movement of landfill gas. | flowpaths may align and adversely impact on the hydraulic conductivity of the overall liner. The appropriate layer thickness also depends on the degree of uniformity of moisture conditioning and compaction that can be achieved by the construction equipment. If it is necessary to tie in new sections of a soil liner into an existing liner, lateral extension should be made about 3–6 m into the existing liner in a stair stepped manner following the individual layers of the existing liner. Materials forming the existing liner must be scarified over a minimum horizontal distance of 1 m to maximise bonding<br>• have a minimum horizontal overlap of 1 m between successive layers to have confidence that a preferential pathway for leachate flow is not being created.<br>(Note: the geotechnical testing authority is required to assess the integrity of the bond between episodes of liner construction at a similar elevation. Further information on material properties and the method of construction for clay liners is presented in Attachment 3)<br>• have a smooth final surface that is graded at a minimum of 2% towards drainage lines and 1% along drainage lines<br>• involve maintenance of the integrity of successive layers and the completed liner. This includes prevention of disturbance, erosion and desiccation cracking<br>• have a construction quality assurance (CQA) plan developed and implemented as a means of managing quality during construction and reporting, so that the materials used, construction methods and completed works comply with the landfill design. (Refer also to Section 11: 'Construction quality assurance for landfill facilities').<br>Geosynthetic materials may be required as an alternative or as a supplement to a clay liner depending on site-specific circumstances.<br>A composite geomembrane and clay liner may be required to safeguard the protected environmental values of surface water or groundwater at sites with a high potential for leachate generation, sensitive values of surface water or groundwater and unfavourable ground conditions. For example, sites with these conditions in the southeast of South Australia may require a composite geomembrane and clay liner to safeguard the protected environmental values of waters. The geomembrane must be placed in intimate contact with the underlying clay. A geosynthetic clay liner (GCL) or similar may be required as an alternative to a clay liner in a composite lining system where it is not practical or economic to source suitable clay materials.<br>Design considerations for geosynthetic materials include hydraulic conductivity, defects, strength, geotechnical stability and the interface with underlying or overlying materials. Considerations also include subgrade preparation, resistance to puncture or degradation during construction and operation, connection of panels, anchorages and construction quality assurance of the materials, placement and connections (see also Section 7, 'Use of geosynthetic materials in base liner systems')<br>Penetrations must not be made through the base liner system. Penetrations through side or cap lining systems are not encouraged and must be designed so that the liner integrity is maintained and a pathway is not created for escape of leachate or landfill gas. |
| Design and construct a leachate drainage layer at Class SB+, MB-, MB+ and L sites.<br>This is to promote | Class SB+, MB-, MB+ and L sites must have a blanket granular drainage medium that comprises the following:<br>• minimum thickness of 0.3 m<br>• as-placed drainage stone hydraulic conductivity greater than $1x10^{-3}$ m/s |

| Suggested measure | Considerations and details |
|---|---|
| collection of leachate and control the maximum head of leachate on top of the liner to less than 0.3 m.<br><br>The integrity of the collection system must be maintained and include resistance to physical and biological clogging. | • clean, hard, durable, sound gravel<br>• $D_{85}$ of not less than 37 mm, $D_{10}$ of not less than 19 mm, uniformity coefficient of less than 2.0 and not more than 1.0% (by weight) of stone may pass a 0.075 mm sieve (AS 1289.1.1-2001).<br>(Note: it is further suggested that a theoretical analysis be conducted to assess the potential range of initial porosity and hydraulic conductivity for a drainage material with a gradation of particle sizes within a coarser size range and results could be used to assess the long-term performance of the collection system with a gradation of size)<br>• material that is free of clay, organic matter or other deleterious material and not subject to physical or chemical degradations by leachate<br>• material that contains less than 15% calcium carbonate by volume<br>• material that is not soluble in acid (test method AWWA B 100.96).<br>(Note: the selection of which test method best suits the analysis of a particular drainage layer material is dependent upon the characteristics of the material. As a guide ISO 10694:1995 & ISO 14235:1998 can be used to determine organic carbon and indirectly estimate the organic matter content of a sample. The direct measurement of organic matter via loss-on-ignition is an acceptable and routinely used method. Inorganic carbon should be determined utilising ISO 10693: 1995 and results should be presented as a percentage of calcium carbonate within the soil sample. A vast array of methods exists for the analysis, so the above methods are encouraged but are not the only available methods. Results utilising other methods can be accepted based upon their merits)<br>• a program of construction quality assurance (see Section 11: 'Construction quality assurance for landfill facilities').<br><br>(Note that a synthetic drainage layer with an equivalent performance may be considered as an alternative—see Section 14 for more information on the process of developing alternative measures.)<br><br>Class SB+, MB-, MB+ and L sites must include leachate collection pipes within the drainage blanket. The spacing and sizing of leachate collection pipes must be designed to control the potential depth of leachate on top of the base liner to less than 0.3 m.<br><br>The design must consider the base liner gradients, drainage aggregate, estimated leachate generation and long-term performance. Typical pipe spacing is between 25 and 40 m.<br><br>Pipe sizing must take into account potential leachate flow, strength, inspection and maintenance and the issues presented above. Pipes must be resistant to degradation by leachate and landfill gas and must be manufactured from HDPE or MDPE. The sizing of leachate pipes is based on leachate flow rates within the pipe and the diameter required for the passage of remote inspection and cleaning equipment. This equipment typically requires pipe diameters greater than 150-200 mm. Manning's equation should be used to derive the required pipe size based on leachate flow rates and pipe slopes. Leachate flow rates are derived from a water balance model.<br><br>Pipe perforations should include 12 mm diameter holes. The hole locations should be alternated in pairs at 150 mm intervals along the pipe. Each alternate pair of holes should be located at 45 and 225 degrees to the vertical axis (pair 1) and 135 and 315 degrees to the vertical axis (pair 2).<br><br>Leachate collection pipes must drain at a minimum grade of 1% to a sump. The minimum slope of the surface of the underlying liner is 2% towards drainage lines. The pipes must extend across the base and up the sides of the landfill |

| Suggested measure | Considerations and details |
|---|---|
| | cell and be able to be inspected and maintained.<br><br>The system needs to maintain its integrity under the vertical loads and stresses from the overlying waste and operating equipment. This will require design of access for vehicle traffic to the cell and procedures for placement of the initial layer of waste.<br><br>Class MB+ and L sites must have a geotextile separation layer between the overlying waste and drainage layer to prevent migration of solids from the waste and clogging of the drainage layer. |
| **Leachate sump** | The sump must be located at the lowest point of the cell to facilitate monitoring and removal of leachate so that the maximum head of leachate on top of the base liner is less than 0.3 m.<br><br>Design considerations include access for monitoring and inspection, leachate generation volumes, operation of pumping equipment (including the depth and storage volume for leachate), connection to the leachate storage and treatment facilities and maintenance of integrity during landfill operation. |
| **Leachate storage and treatment** to prevent pollution of surface water and groundwater, odour and to minimise human contact. | Assessment of options for leachate storage and treatment will need to consider the quantity and composition of leachate. Possible treatment options include evaporation, degradation by aerobic bacteria or chemical or physical treatment.<br><br>Design of the leachate storage capacity will need to consider the potential leachate generation, rainfall, climatic conditions, the risk of overtopping and treatment options. Other design considerations include odour management and control of access.<br><br>The leachate evaporation pond needs to be designed with sufficient surface area to ensure that the system can accommodate the volume of leachate generated over a year. This can be calculated using the following formula:<br><br>A = 1000 V/0.8E-R<br><br>A: leachate pond surface area<br><br>V: annual volume of leachate (kL)<br><br>E: median annual evaporation (mm class A-pan)<br><br>R: median annual rainfall (mm)<br><br>Leachate storage for Class SB+, MB+ and L sites must be in a dedicated detention pond separate to the landfill cells. The pond should be designed with a minimum freeboard of 0.6 m. The suggested leachate evaporation pond needs to be designed and constructed to a technical standard equivalent to the landfill base liner. This is overlain by a geomembrane placed in intimate contact with the underlying clay. Considerations for subgrade preparation and design and construction of clay liners and geosynthetic materials are presented above.<br><br>For sites with a lower risk of leachate generation (Class SB- and MB-), it may be possible to have temporary storage of leachate and treatment by evaporation in an enlarged sump within the landfill cell. This approach will need to consider the risk of inundation of the waste or escape of leachate and contingency plans to manage these risks. It must also limit access to the area to minimise the risk of impact to the health of humans or animals. |

**Table 4 Summary of landfill and suggested measures for the leachate collection and containment system for landfill facilities accepting municipal solid waste and commercial and industrial general waste**

| Landfill type based on waste disposal | SMALL<br>(only considered if it is not possible to participate in a regional waste management concept) | | MEDIUM | | LARGE |
|---|---|---|---|---|---|
| Total tonnes capacity | <26,000 | | >26,000 and <130,000 | | >130,000 |
| Landfill classification | SB- | SB+ | MB- | MB+ | L |
| Summary of suggested measures for the leachate collection and containment system | Waste body | Waste body | | Waste body | |
| | 150 mm base preparation layer of reworked soil | 300 mm leachate collection layer (blanket) including leachate collection pipes within the drainage blanket | | Geotextile | |
| | In situ soil | 600 mm thick compacted clay with $k \leq 1x10^{-9}$ m/s (minimum of 3 layers of 200 mm compacted thickness each)<br>(a composite lining system that includes a geomembrane overlying the clay may be required at some sites to safeguard the protected environmental values of surface waters or ground water) | | 300 mm leachate collection layer (blanket) including leachate collection pipes within the drainage blanket | |
| | | 150 mm subgrade preparation | | 1000 mm thick compacted clay with $k \leq 1x10^{-9}$ m/s (minimum of 5 layers of 200 mm compacted thickness each)<br>(a composite lining system that includes a geomembrane overlying the clay may be required at some sites to safeguard the protected environmental values of surface waters or ground water) | |
| | | In situ soil | | 150 mm subgrade preparation | |
| | | | | In situ soil | |

# 7 USE OF GEOSYNTHETIC MATERIALS IN BASE LINER SYSTEMS

Geosynthetic materials may be considered as an alternative or supplement to a compacted clay liner as part of an engineered barrier layer in a landfill base liner.

This section aims to provide direction and consistency for use of geosynthetic materials (geosynthetics) for design and construction of base liner systems for landfills accepting municipal solid waste and commercial and industrial general waste.

Some landfill facilities may consider use of geosynthetics in base liner systems as an alternative to, or to improve the performance of, a compacted clay liner as part of an engineered barrier layer for the base and side of the landfill. Geosynthetics may be more appropriate for some site-specific circumstances due to the nature, availability or practicality of using clay materials; the nature of the waste; the landfill geometry; and climatic conditions. A base and side liner including geosynthetics may be required to safeguard the protected environmental values of surface water and groundwater at sites with a high potential for leachate generation, sensitive values of surface water or groundwater, or unfavourable ground conditions.

Geosynthetics used in a base and side liner may also include materials used to control migration of fines (separation layer), to cushion point loads and for reinforcement. This section considers the use of geosynthetics as a barrier system only.

Geosynthetics used as part of the barrier system may include:

- geomembranes in conjunction with a compacted clay liner
- a geosynthetic clay liner (GCL) in conjunction with a compacted clay liner
- a geomembrane in conjunction with a GCL.

The system of using a geomembrane in conjunction with a compacted clay liner is called a composite liner. The system of using a GCL with a compacted clay liner is an augmented liner.

(Note that the objectives, required outcomes and suggested measures for design and construction of leachate containment and management systems are presented in Section 6. Section 6 also includes use of a compacted clay liner as an engineered barrier layer to promote leachate collection. Information on geosynthetics, as they relate to use in capping systems, is presented in Section 10.)

## 7.1 Objectives

The objectives of using liners incorporating geosynthetics in base liner systems for landfill facilities are to provide an equivalent or better level of environmental protection than the minimum requirements for base liner systems set by the EPA. Based on a risk assessment of site conditions, composite or augmented liners may be required to provide an enhanced level of protection to manage environmental risks.

## 7.2 Required outcomes

The required outcomes for use of geosynthetics in a base and side liner are as follows:

- The performance of liners incorporating geosynthetics must be equivalent or better than the minimum compacted clay liner system, as specified in Section 6: 'Leachate containment and management systems'. Demonstration of equivalence should be in terms of risk to the environment (see Section 14 for more information).
- The design of the geosynthetics liner should endeavour to keep the liner 'de-stressed' wherever possible. The function of the liner is to limit seepage, and it should not be subject to significant tensile stresses.
- Penetrations for inlet and outlet pipes or other penetrations through the liner should be avoided where possible. Penetrations must be designed and constructed so that the liner integrity is maintained.
- The long-term factor of safety against slope instability must be ≥ 1.5.
- The factor of safety against slope instability of temporary (less than two years) slopes must be ≥ 1.3.
- The performance of the lining system should be modelled for a period of 100 years.

## 7.3 Considerations related to geosynthetic liners

The inclusion of geosynthetic materials in a base and side liner must take into account the following (further details to follow):

- appropriate design of the system, to provide the required level of environmental protection
- general construction considerations for using specialist materials
- durability of the materials.

### 7.3.1 Design considerations

The design of a geosynthetic liner must include the following considerations:

- Materials placed over geosynthetic liners can be unstable. Generally, the interface friction of geosynthetic liners is very low, resulting in a preferential sliding plane: the interface friction of textured geomembranes is generally higher and may require complex stability analysis. Stability issues may exist at side liners and at the edge of landfill cells, where interim or permanent waste slopes may be constructed. Where appropriate, laboratory testing of geosynthetics in conjunction with the proposed construction materials should be considered to determine the interface friction over the likely confining stress range.
- Stresses and strains resulting from imposed loads on the liner system are applied to the geosynthetics both from waste placed over the liner and from construction loads. The design must consider the total load applied from the full thickness of the waste and landfill cap. The impact of point loads from the gravel of the leachate collection layer must be considered when assessing the cushioning required to protect geosynthetic liners. Imposed loads may also result from settlement and movement of the waste adjacent to a side liner of the landfill. Settlement of the subgrade soils (underlying the liner system) may also occur, resulting from the imposed load of the overlying waste, which may be significant.

- Once covered with waste, the liner system cannot be accessed for repair and maintenance without significant cost and impact on operations.
- Seepage through the liner is a primary design consideration and is related to materials selected, thicknesses, seepage management, installation control and geometry of the base and side liner. Measures to reduce seepage include
  - a composite liner (better than a single liner)
  - lower permeability of the underlying layers
  - a thicker liner (better than a thinner liner)
  - a low hydraulic head over the liner.
- Chemicals and temperature have impacts on the liner system as part of the leachate collection system or from landfill gas. Temperatures in excess of 40 °C commonly occur in large landfill facilities due to decomposition of the waste.
- Traffic over geosynthetic liners during installation should generally be limited. The risks and impact of construction activities must be considered in the design to limit defects in the liner which would result in increased seepage through the system.
- Special details such as penetrations, joins to other materials, staging of works, anchorage, edge effects around the perimeter of cells and the join detail of the side liner to the cap should be considered.
- Static loads and the geometry of the leachate collection sump structure can affect the underlying geosynthetic liner system. Settlement of the waste can cause downward forces on sump riser pipes which can be transferred to liner components.
- Joining future extensions usually requires exposing existing geosynthetics. Exposing geosynthetics without damage requires careful consideration, including recognition of the potential presence of leachate over the existing liner system.
- Demonstration of equivalence of the lining system should take into consideration issues such as flow rate and concentration gradients with respect to time, related to the point of compliance for the site (see Section 14 for more information).

### 7.3.2 Construction considerations

The construction of the geosynthetic liner and the underlying and overlying materials must be carried out in accordance with an effective quality control and quality assurance program (see Attachment 4). Poor installation can neutralise the potential benefits of a geosynthetic liner system.

Construction must at least consider the following points:

- good subgrade preparation to provide a sound and stable base for liner construction
- the quality of the geosynthetic liner delivered to the site
- the quality of joins
- the risk of damage during handling, storage and installation, including that due to weather conditions, e.g. wind, rainfall and temperature
- provision of intimate contact between the geosynthetic and underlying materials where appropriate, including prevention of wrinkles in the geosynthetic
- construction staging that considers timely placement of materials that act as protection and surcharge over the geosynthetic

- stormwater management during construction, as geosynthetics placement requires relatively dry conditions—particular consideration is required for lining leachate collection sumps located at the lowest point of a base liner
- appropriate access and practical requirements to enable placement of a geosynthetic side liner and joining of geosynthetics on slopes
- the risk of subsequent damage from other construction activities, such as placement of materials over the geosynthetic liner
- stormwater management on side slopes to prevent infiltration under the liner system.

### 7.3.3 Durability considerations

Durability issues are related to the environment of the geosynthetic liner. The durability considerations of GCLs and geomembranes are different.

Geomembrane considerations must include the:

- chemical resistance to leachate
- temperature around the liner.

GCL considerations must include the:

- risk of degradation of reinforcement fibres
- chemical effect of leachate on GCL materials
- stability of bentonite under high loads.

## 7.4 Suggested measures

### 7.4.1 Acceptable systems

Liner systems that incorporate the following geosynthetics are considered to be acceptable for use as a barrier layer in a landfill base and side liner:

- a compacted clay rich liner augmented by a geosynthetic clay liner (GCL)
- a composite liner comprising a geomembrane liner underlain by a GCL or a compacted clay liner—an engineered subgrade is required under the GCL.

The geosynthetic base and side liner system must be considered on a case-by-case basis. Acceptable geosynthetic liners include reinforced GCL and reinforced and unreinforced geomembranes. Acceptable materials for geosynthetic liners include:

- GCL manufactured from polyethylene, polypropylene or polyester geotextile or geomembrane substrate and preferably sodium bentonite—selection of calcium bentonite filling for the GCL may be considered but the minimum requirements in this guideline are related to use of sodium bentonite in the GCL
- high density polyethylene (HDPE) geomembrane.

Other materials may be considered for the base and side liner where the expected quality of the leachate is more predictable than landfill leachate from a mixed waste stream.

Geomembranes made from the following materials may be considered, depending on chemical and temperature considerations:

- linear low density and medium density polyethylene
- polypropylene
- PVC
- synthetic rubber
- ethylene alloy.

Objectives, required outcomes and suggested measures for construction of compacted clay liners are presented in Section 6: 'Leachate containment and management systems'.

### 7.4.2 Minimum requirements

The geosynthetic liner system for the base and side liner must be designed by a person with demonstrated understanding of and experience in the design and installation of the proposed geosynthetics, and in the geotechnical considerations related to lining the base of landfills. The installation of the geosynthetic liner must be carried out in accordance with an effective construction quality assurance (CQA) system (refer to Attachment 4), as developed in consultation with the EPA before commencement of construction. The EPA approved CQA plan may only be varied in consultation with the EPA.

Based on the materials discussed in Section 7.4.1 and installation requirements, the following parameters are considered minimum requirements for geosynthetic liners in base liner systems.

*Geosynthetic clay liner GCL*

The minimum thickness of the GCL shall be 7 mm, measured at a moisture content of less than 10% by weight.

The GCL should include a layer of geotextiles over the top and bottom of the bentonite. The GCL should be reinforced, which means the top and bottom geotextiles are linked to provide tensile capacity across the bentonite layer in the GCL. The tensile strength of the linking is a design parameter for the GCL, but for installation purposes should be greater than a peel force of 300 N/m.

In addition, the following minimum requirements must be satisfied:

- overlaps of the GCL panels must provide a similar seepage control performance as the rest of the GCL
- particles in contact with the GCL must be less than 15 mm in any dimension, with protrusions limited to less than 10 mm
- the GCL shall not be joined along slope lengths with grades steeper than 1 vertical (V) in 5 horizontal (H).

*Geomembrane*

The minimum requirements for geomembranes are related to commonly adopted applications for base and side liners for landfills, and do not relate to specifically engineered geomembranes for special applications or mono waste stream landfills. Geomembrane liners for base and side liners should satisfy the minimum requirements as shown in Table 5.

**Table 5 Minimum requirements for geomembrane liners for landfill base and side liners**

| | |
|---|---|
| Thickness of geomembrane | 1.50 mm |
| Strain before rupture or break | > 50% |
| Minimum tensile strength at rupture | > 10 kN/m |

In addition, the following minimum requirements must be satisfied:

- joins must be permanently bonded, taking into consideration the geomembrane type, e.g. heat bonding for HDPE geomembranes
- the geomembrane must be installed in intimate contact with the underlying layer.

Further to the above criteria, Tables B1 and B2 in Attachment 5 present minimum properties for various geosynthetic liner materials commonly adopted for base and side liners (HDPE and GCL). These properties should not replace design of the liner but are provided as a guide related to survivability during installation and joining.

### 7.4.3 Suggested liner systems

The following liner systems may be considered for base and side liners:

1. Geomembrane and GCL composite liner with
   - leachate drainage layer 300 mm thick
   - 350 g/$m^2$ cushion of non-woven geotextile
   - 1.5 mm thick HDPE geomembrane
   - GCL
   - 200 mm engineered clayey subgrade layer
   - in-situ subgrade above the water table—the minimum required distance between the engineered subgrade and the water table should be decided based on site-specific risks.
2. Geomembrane and compacted clay liner with
   - leachate drainage layer 300 mm thick
   - 350 g/$m^2$ cushion of non-woven geotextile
   - 1.5 mm thick HDPE geomembrane
   - 500 mm thick compacted clay liner placed in a maximum of three layers
   - the minimum required distance between the underside of the compacted clay liner and the water table should be decided based on site-specific risks.
3. GCL and compacted clay liner with
   - leachate drainage layer 300 mm thick
   - GCL
   - 200 mm thick compacted clay liner
   - in-situ subgrade above the water table—the minimum required distance between the engineered subgrade and the water table should be decided based on site-specific risks.

Limitations on the maximum particle size over the GCL limit the choice of aggregate for the leachate collection layer. Due to the risk of biological blocking by smaller particles within the aggregate, the GCL and compacted clay liner option may only be considered for liners in Type B– areas. Details of landfill classification based on site conditions (Type B+ or B–) are presented in Section 2 of this guideline.

Design of the cushion geotextile must consider the nature and weight of overlying materials and, therefore, may differ from the types discussed earlier in this section.

# 8 MANAGEMENT STRATEGIES FOR LANDFILL GAS AND AIR QUALITY

Degradation of putrescible waste in a landfill generates methane, carbon dioxide and other trace gases that pose potential hazards to site safety, human health and the environment. Generation of landfill gas can continue for tens of years after placement of the waste. Odour, dust and leachate from landfill operations have the potential to cause nuisance and health problems. Therefore, management strategies for these issues will need to be developed for landfill design, operation and the post-closure period.

## 8.1 Background to landfill gas and air quality

Methane is explosive when it is present in the range of 5% (lower explosive limit) and 15% (upper explosive limit) by volume in air. Methane or carbon dioxide can also be an asphyxiant if present in excessive concentrations. Landfill gas poses a potential explosion or asphyxiation hazard by migrating from the waste (for example, through the landfill surface, granular layers, man-made underground trenches, service conduits or similar) and accumulation in confined spaces or work spaces.

Methane and carbon dioxide are greenhouse gases. Methane has 21 times the effect of carbon dioxide on the 'greenhouse effect' and related climate change. Management strategies can include measures to promote oxidation of methane to water and carbon dioxide to provide a net reduction of greenhouse effects.

Methane and carbon dioxide are odourless. However, other components of landfill gas can be very odorous and impact on amenity.

(Note: relevant legislation and regulations for landfill gas and air quality can be found in **the** *Environment Protection Act 1993* and *Environment Protection (Air Quality) Policy 1994).*

## 8.2 Objective

The objective of management strategies for landfill gas and air quality is to manage potential hazards, adverse environmental impacts and potential loss of amenity from landfill gas, dust and odour during landfill operation and post-closure.

## 8.3 Required outcomes

The required outcomes for management strategies for landfill gas and air quality include:

- prevention of adverse impacts from on-site and off-site migration and emissions of landfill gas
- limitation of gas concentrations in monitoring bores at the boundary of the landfill facility or within structures located on or off site to less than 1% methane by volume or 1.5% carbon dioxide by volume
- minimisation of greenhouse gas emissions as much as reasonably practicable
- sustainable utilisation of landfill gas as much as reasonably practicable
- management of potential hazards from asphyxiation or explosion in areas accessed by humans and in structures, equipment and other facilities
- prevention of nuisance or offence from odorous emissions or dust

- management of airborne impurities, pathogens and toxins so that they do not pose an unacceptable health risk to the community
- monitoring of landfill gas migration and emissions and remediate emissions that pose risks to the community or facilities.

## 8.4 Suggested measures

### 8.4.1 Landfill gas and odour

Management strategies for landfill gas and odour will need to be developed to manage potential hazards and adverse impacts on amenity and the environment during landfill operation and post-closure. Strategies may need to vary during operation and during the post-closure period. Considerations include the following:

- management of the amount and disposal of green and other putrescible or odour-generating wastes and options for avoidance, reduction and recycling
- potential generation of landfill gas. This will need to take into account the quantity, geometry, composition, moisture condition and age of the waste together with changes in landfill gas generation and composition with waste degradation and time. Generation of landfill gas can occur for tens of years after waste disposal. Generation rates typically increase to a peak, after which they decrease with time. A preliminary assessment of landfill gas generation rates can be carried out using landfill gas models. An example of a landfill gas model is GasSim *(*Environment Agency, United Kingdom, 2002). Another example is the LandGEM model prepared by the US Environmental Protection Authority. Default parameters for use in the LandGEM model have been published for Australian conditions (National greenhouse gas inventory committee 1996). Further assessment of landfill gas generation would include field testing and monitoring.
- the proximity of the waste to residences, buildings, people and other potential receptors. Particular attention will be required where receptors are located near the waste
- climate and wind conditions at the landfill site
- the risk of off-site migration of landfill gas based on subsurface soils, rocks and karstic limestone, old mining works and landfill lining and capping systems. Particular attention will be required at sites with granular soils, sand lenses, fractured rocks or similar that provide pathways for lateral migration of landfill gas
- potential hazards that may impact on human health, buildings or facilities. This includes explosion or asphyxiation hazards. This may require special design measures for access, equipment, structures, services and ventilation systems for buildings or workspaces
- reduction of greenhouse effects by control of fugitive emissions and oxidation of methane to carbon dioxide. Options for methane oxidation include collection and combustion by controlled flaring or by an engine or turbine (see Section 8.4.2). Options also include oxidation by bacteria in the landfill cover that can be enhanced by careful cap design and maintenance (including addition of suitable organic material and control of moisture conditions). For large landfills a gas extraction system should be installed, with oxidation in the cap being an adjunct to extraction. For small landfills, oxidation of methane through the cap may be acceptable. Medium sized landfills may need to be assessed on a case-by-case basis.

- opportunities for utilisation of the gas. Options may include direct utilisation by industry or as an energy source for heat production or electricity generation. Design and operation of utilisation systems must be carried out in conjunction with the overall management strategy. It must not reduce obligations for management of potential hazards and adverse impact on human health, the environment or amenity on the site or off site.
- distress of vegetation on the landfill cover and around the landfill perimeter
- monitoring to assess potential hazards, the performance of the management strategy and measures and items for improvement. This includes observation of vegetation distress, odour, surface conditions and measurements of landfill gas in monitoring bores and areas where landfill gas may accumulate and pose a hazard. Monitoring points may need to be located near structures, the site boundary and other sensitive facilities. The monitoring program should include the frequency, scope, quality assurance (QA) procedures, documentation and recommendations for corrective actions, improvement and management review.
- site health and safety, including access and safe work procedures.

### 8.4.2 Landfill gas collection and combustion

Landfill gas can be managed by either an active or passive gas collection system. Systems for active landfill gas collection and combustion are required to reduce greenhouse gas emissions, for gas utilisation, odour control or as part of the risk management strategy.

Systems of landfill gas collection and combustion are required by the EPA as an effective measure to achieve the objectives and required outcomes of this guideline, unless justified otherwise. Similarly, gas recovery and utilisation for beneficial purposes is encouraged.

Design and operation of the collection and combustion system will need to consider the following:

- optimisation of the quality and quantity of gas collected
- operating hours and a backup/contingency plan for periods of maintenance or other down time
- extraction wells including the layout, orientation (vertical and/or horizontal), design, area of influence, flow control mechanisms and monitoring points. Wells must not penetrate or impact on the integrity of base or side liner systems. The integrity of the landfill capping system must also be maintained
- monitoring wells and points may need to be installed at different levels, depending on site-specific conditions to ensure that high-level concentration areas are detected
- the collection system between the extraction wells and combustion system, including pipework, vacuum source, flow control facilities, monitoring and condensate management
- protection and maintenance of the integrity, operation and durability of system components. Considerations include corrosive gas, landfill leachate, condensate, vandalism, stresses from surcharge loads and settlement of the waste
- the risk of air intrusion and potential explosion and fire hazards
- control of air emissions from the combustion system to comply with the *Environment Protection (Air Quality) Policy 1994* and reduce volatile organic compound emissions by 98%. Design of the flare systems will need to consider retention time, temperature, ignition control and flame arresters

- design, operation, maintenance and monitoring by trained personnel
- management of access to the system infrastructure
- operation and maintenance during landfill operation and post-closure

  (Note: further assessment will be undertaken regarding buffer distances between closed landfills where landfill gas is identified as an issue as well as for new landfill developments).

### 8.4.3 Dust management

Dust created within the landfill property must be controlled to prevent off-site and on-site impacts including environmental nuisance. Areas susceptible to dust generation include areas of land disturbance, vehicle traffic, dusty waste and soil stockpiles.

Measures to manage dust include:

- wind abatement systems including vegetation or embankments
- covering of vehicles containing dusty loads
- control of traffic movements on designated roadways
- placement of compacted quarry granular materials and possible sealing on regularly used roads
- limiting the extent of disturbed areas and soil stockpiles, control of their orientation (with respect to prevailing wind directions) and covering with vegetation
- use of water or other dust suppressants.

# 9 CAPPING SYSTEMS

This section aims to provide direction and consistency for design and construction of capping systems for landfills accepting municipal solid waste and commercial and industrial general waste.

Capping systems play an important role in closure and post-closure care of landfill cells. This includes management of land use and amenity, management of surface water, limiting of leachate generation and control of landfill gas.

## 9.1 Objectives

The objectives of capping systems for landfill facilities are to:

- provide a long-term and stable separation layer between the waste and the final surface that protects human health and the environment
- minimise the generation of leachate
- safeguard the protected environmental values of surface water and groundwater in accordance with the *Environment Protection (Water Quality) Policy 2015*
- assist with the management of hazards associated with landfill gas
- assist with limiting greenhouse gas emissions to the atmosphere
- assist with the control of odour emissions from the site
- provide land that is compatible with the intended after-use.

## 9.2 Required outcomes

The required outcomes of capping systems for landfill facilities are to:

- design and install a landfill cap over the full footprint of the site covered by waste
- limit seepage of water through the landfill cap to less than the anticipated seepage through the landfill base
- design and construct the cap to limit the opportunity for rainfall infiltration and therefore the generation of leachate, and to safeguard the protected environmental values of surface water and groundwater
- design and construct the cap to be compatible with the landfill gas management system, and the principles of the guideline on landfill gas management
- install a capping system that can be maintained and will continue to meet the objectives and required outcomes.

## 9.3 Suggested measures

### 9.3.1 Design of the capping system

The suggested measures for capping systems include an engineered barrier layer overlain by a protection layer and a growing medium with suitable vegetation. Options for the barrier layer include use of a compacted clay liner and/or use of geosynthetics.

(Section 9.3.4 also includes suggested measures for assessment of alternative capping systems that do not include an engineered barrier layer, where the design is based on water storage and release principles.)

Design of the capping system must consider the following:

- the final shape (landform) as outlined in the closure guideline
- capping the full footprint of the site covered by waste and extending the capping system laterally to link in with the surrounding ground
- integration with other environmental protection measures that exist on site, e.g. base and side liner systems, landfill gas management systems, leachate management systems
- guidance on assessment of the environmental setting and water management strategies (to safeguard the protected environmental values of surface water and groundwater) as presented in Section 5: 'Environmental assessment and water management strategies'. This includes assessment and consideration of site conditions (e.g. geometry, climate, hydrogeology, surface water and drainage) and results of monitoring programs during landfill operation (e.g. surface water and groundwater)
- promoting runoff of precipitation while controlling erosion
- designing the cap for all landfill cells (including those that do not include a base liner and leachate collection system) to minimise infiltration of water through the cap. This will minimise the risk of a build up of leachate in the waste: i) where the landfill base includes a liner and leachate collection system, or ii) in unlined facilities that have a low permeability foundation
- limiting migration of landfill gas both on and off site, with the associated risk of asphyxiation (death by gassing) of vegetation; limiting uncontrolled accumulation and concentration of landfill gas, with the associated risk of ignition; and limiting uncontrolled landfill gas emissions to the atmosphere
- construction materials (e.g. properties, quantity, management, handling, placement and construction quality assurance)
- maintenance of the cap integrity and long-term performance of the cap according to differential settlement (subsidence of the landform), vegetation, climatic conditions, changes in moisture content of the barrier system, etc.
- landfill edge effects, protrusions (landfill gas extraction wells) and zones with thicker or younger waste that may undergo greater settlement than areas with older waste
- geotechnical slope stability—considerations include temporary and permanent slopes, drainage, lateral seepage on the underside of the liner system, interface strength parameters of lining systems and overall landfill stability
- subgrade conditions (prepared surface of the landfill and surrounding areas prior to installation of the cap), and site preparation to provide a sound and stable subgrade for cap construction
- access for maintenance and monitoring of the capping system.

### 9.3.2 Caps incorporating barrier systems

The suggested measures for the engineered barrier layer in this guideline include a compacted clay liner. Use of geosynthetics in capping systems as an alternative or supplement to a compacted clay liner are presented in Section 10: 'Use of geosynthetic materials in capping systems'.

### 9.3.3 Caps incorporating a compacted clay liner

Suggested measures to achieve the objectives and required outcomes for construction of a cap incorporating a compacted clay liner are presented in Table 6. Some measures are subject to the site classification, which is based on the waste stream and the site conditions. The method used to assess the site classification is presented in Section 2: 'How to use this guideline'.

The suggested cross-section profile for the capping systems for each site classification is summarised in Table 7.

**Table 6 Suggested measures for a capping system that includes a compacted clay liner and overlying protection layer**

| Suggested measure | Considerations and details |
|---|---|
| Investigation of geotechnical aspects for design and construction of the capping system. | Considerations include subgrade conditions for cap construction, geotechnical slope stability and potential earthworks construction materials.<br>Slope stability considerations include temporary and permanent slopes, interface strength parameters of lining systems and global landfill stability.<br>Earthworks construction materials include those suitable for a compacted clay liner, drainage layer, subsoil, growing medium and other fill, as appropriate. Further considerations and details for assessment of clay materials are presented in Attachment 3. |
| Site preparation to provide a sound and stable subgrade for cap construction and to promote surface drainage. | The subgrade should comprise a minimum thickness of 0.3 m of cover soil over the waste. The subgrade surface should promote runoff of surface water during construction and be shaped similarly to the final landfill surface, subject to stability considerations (refer to considerations for the final landform in Section 12: 'Closure and post-closure plans')<br>The prepared subgrade should be proof-rolled to assess the presence of zones that may require subgrade improvement.<br>Subgrade improvement may be required in the following areas:<br>• if there is a risk of differential settlement that may have an adverse impact on the integrity or long-term performance of the cap<br>• to provide a sound platform for subsequent cap construction.<br>Subgrade improvement works should follow sound engineering principles and be carried out in accordance with a construction quality assurance plan. Improvement measures may include placement of coarse granular materials or use of geosynthetics to provide reinforcing.<br>Use of fill placement to raise subgrade levels must consider the potential total and differential settlement. |

| Suggested measure | Considerations and details |
|---|---|
| Design and construction of an engineered barrier layer over the waste for Type SB+, MB-, MB+ and L sites.<br><br>The purpose of the barrier layer is to:<br>• promote collection of landfill gas<br>• reduce emissions of landfill gas<br>• retard generation of leachate to levels that safeguard the protected environmental values of groundwater or surface water. | If a compacted clay liner is used, it must comprise:<br>• a minimum compacted total thickness of 600 mm of material with a minimum of three layers of 200 mm compacted thickness each<br>• a hydraulic conductivity of less than $1 \times 10^{-8}$ m/s for Type SB+ and MB- sites and less than $1 \times 10^{-9}$ m/s for Type MB+ and L sites<br>• construction by uniform moisture conditioning and uniform compaction using a sheepsfoot roller in layers with a maximum thickness of 200 mm. There must be effective bonding between successive layers that includes kneading between layers and scarification and moisture conditioning between successive layers. The specification of maximum layer thickness and the number of layers is intended to promote uniformity within each layer and reduce the probability that preferential flow paths may align and have an adverse impact on the hydraulic conductivity of the overall barrier layer. The appropriate layer thickness also depends on the degree of uniformity of moisture conditioning and compaction that can be achieved by the construction equipment. If staged construction of each layer is carried out, the joins between episodes of layer construction must be offset at a minimum horizontal distance of 3 m between successive layers. Further information on material properties and the method of construction for clay liners is presented in Attachment 3<br>• development and implementation of a CQA plan as a means of managing quality during construction, and of reporting that the materials used, construction methods and completed works comply with the landfill design (see also Section 11: 'Construction quality assurance for landfill facilities')<br>• maintenance of the integrity of successive layers and the completed compacted clay liner. This includes prevention of disturbance, rutting, erosion, softening and desiccation cracking.<br><br>Penetrations through barrier layers in the cap are to be avoided if feasible. Where penetrations are required, they must be designed so that the barrier layer integrity is maintained and a pathway is not created for infiltration of water or escape of leachate or landfill gas.<br><br>Geosynthetic materials may be required as an alternative or supplement to a compacted clay liner, depending on site-specific circumstances (see also Section 10: 'Use of geosynthetic materials in capping systems').<br><br>A geosynthetic liner may be required to safeguard the protected environmental values of surface water or groundwater at sites with a high potential for leachate generation, sensitive values of surface water or groundwater and unfavourable ground conditions (e.g. in the South East of South Australia). |

| Suggested Measure | Considerations and details |
|---|---|
| Design and construction of a protective layer and growing medium that includes a subsoil layer and a topsoil layer that supports vegetation to:<br>• promote evapotranspiration<br>• control erosion<br>• provide protection to prevent exposure, desiccation cracking and disturbance of the underlying barrier system<br>• promote oxidation of methane seeping through the cap. | The protective layer and growing medium must comprise:<br>• a minimum thickness of 100 mm of topsoil comprising silty sand, sandy silt, clayey sand or sandy clay with organic matter (naturally occurring, mulch or compost)<br>• a subsoil layer to provide protection for the underlying barrier layer (from cracking or disturbance), enable moisture storage and release, and assist with sustaining plant roots.<br>The thickness of subsoil must be based on the issues listed below and should be at least 600 mm for Type SB-, SB+ and MB- sites and 800 mm for Type MB+ and L sites. Compaction of or vehicle traffic over these soils should be minimised, to avoid limiting root growth.<br>Considerations must include:<br>• shaping the surface to comply with the final landform as outlined in Section 12: 'Closure and post-closure plans'<br>• the sustainability of the system for supporting vegetation<br>• local climatic conditions and soil profile<br>• use of vegetation compatible with surrounding land uses, habitat and climate<br>• planting of indigenous species<br>• the rooting depth of the vegetation, such that it does not extend into and damage the integrity of the barrier layer. This typically means limiting vegetation to grasses and small shrubs with rooting depths not more than the topsoil and subsoil thickness, and adding thicker covers of soil for areas of trees and small shrubs<br>• prevention of introduction of weeds, plant pathogens and pests<br>• stormwater and erosion control<br>• the water holding capacity and drainage of the subsoils and topsoil. Subsoil drainage may be required in subsoils with limited water holding capacity, areas of high rainfall or caps with shallow surface grades. Subsurface drainage must be considered carefully for Type SB+, MB+ and L sites. Design of subsurface drainage measures will need to consider the cap soil types, vegetation, climatic conditions, surface slopes (grade and length), geotechnical stability, stormwater control systems, post-closure use and activities (e.g. irrigation, access and maintenance) and control of the drainage water. Build-up of moisture within poorly drained cap soils can have an impact on geotechnical stability, vegetation growth and trafficability, and may increase infiltration through the liner and subsequent leachate generation. Risks may be managed at some sites by careful design of slopes, and choice of cap soils and vegetation. Subsoil drainage may comprise a series of subsurface interception strip drains. Some sites may require a blanket subsurface drainage system using pipes laid in a 200 mm thickness of free-draining granular material or a geosynthetic drainage layer<br>• the stability of the soils covering a lower permeability engineered barrier layer with a potential perched watertable<br>• protection from disturbance, or use of sufficient thickness of subsoil for disturbance, by borrowing animals |

| Suggested Measure | Considerations and details |
|---|---|
| | • use of nutrients and organic matter to promote plant growth<br>• a soil contamination status compatible with OHS&W issues during construction and with the post-closure land use<br>• durability of the cap components and surface<br>• maintenance and ongoing management of the growing medium and vegetation<br>• use of a gas distribution layer and thick organic layer to maximise oxidation of methane<br>• a program of CQA—refer to Section 11: 'Construction quality assurance for landfill facilities'. |

**Table 7 Summary of suggested measures for capping systems that include a compacted clay liner as a barrier layer for landfill facilities accepting municipal solid waste and commercial and industrial general waste**

| Landfill type based on waste disposal | SMALL<br>(only considered if it is not possible to participate in a regional waste management concept) | | MEDIUM | | LARGE |
|---|---|---|---|---|---|
| Total tonnes capacity | <26 000 | | >26 000 and <130 000 | | >130 000 |
| Landfill classification | SB- | SB+ | MB- | MB+ | L |
| Summary of suggested measures for capping systems | 100 mm thick topsoil to support vegetation | 100 mm thick topsoil to support vegetation | | 100 mm thick topsoil to support vegetation | |
| | 600 mm subsoil<br>(subsoil drainage may be required—refer to Table 6) | 600 mm subsoil<br>(subsoil drainage may be required—refer to Table 6) | | 800 mm subsoil<br>(subsoil drainage may be required—refer to Table 6) | |
| | In situ waste | 600 mm thick compacted clay liner with $k \leq 1x10^{-8}$ m/s<br>(minimum of three layers of 200 mm compacted thickness each)<br>(a lining system that includes geosynthetic materials may be required at some sites to safeguard the protected environmental values of surface water and groundwater) | | 600 mm thick compacted clay liner with $k \leq 1x10^{-9}$ m/s<br>(minimum of three layers of 200 mm compacted thickness each)<br>(a lining system that includes geosynthetic materials may be required at some sites to safeguard the protected environmental values of surface water and groundwater) | |
| | | 300 mm cover soils over waste to provide a separation layer and sound platform for cap construction | | 300 mm cover soils over waste to provide a separation layer and sound platform for cap construction | |
| | | In situ waste | | In situ waste | |

### 9.3.4 Alternative capping systems

This section includes suggested measures for assessment of alternative capping systems that do not include an engineered barrier layer, where the design is based on water storage and release principles. These might include evaporative type caps or use of a capillary barrier system. (Note that this information should be read in conjunction with Section 14).

The proponent must demonstrate an equivalent or better performance of the proposed alternative system compared with capping systems that include an engineered barrier layer as outlined earlier in Section 9. These systems do not have a long track record, so the emphasis is on demonstrated performance of the proposed system.

Considerations must include:

- the objectives and required outcomes of this guideline
- infiltration of water through the cap (as discussed earlier)
- modelling of moisture movement in unsaturated soils
- the risk and potential consequences of extended dry weather or high intensity rainfall on performance
- plant life cycle effects on the system, for example, roots of dead shrubs
- the issues presented in Table 6 for investigation, site preparation, and design and construction of the protective layer and growing medium
- the durability of the cap components and surface
- landfill gas management and potential effects on vegetation
- use of earthworks materials
- an action plan to select, plant, manage and maintain vegetation and the growing medium.

A field trial to monitor and measure the performance of the proposed system must be undertaken for a minimum of three years and must consider representative climatic conditions for the site. The field trial should be carried out at the site, use the proposed materials and vegetation for the final cap and represent the different topographic conditions of the proposed cap. A shorter time period can be considered by the EPA if the applicant can demonstrate that trial results from comparable sites can be transferred in some circumstances.

Equivalence of an alternative cap system (see Section 14 for process) shall be demonstrated in terms of:

- infiltration into the underlying waste
- accommodation of effects resulting from settlement of underlying waste
- erosion control
- robustness of the cap to moderate variations in management of the system.

# 10 USE OF GEOSYNTHETIC MATERIALS IN CAPPING SYSTEMS

Geosynthetic materials may be considered as an alternative or supplement to a compacted clay liner as part of an engineered barrier layer in a landfill cap. This section aims to provide direction and consistency for use of geosynthetic materials (geosynthetics) for design and construction of capping systems for landfills accepting municipal solid waste and commercial and industrial general waste.

Some landfill facilities may consider use of geosynthetics in capping systems as an alternative to, or to improve the performance of, a compacted clay liner, as part of an engineered barrier layer in the landfill cap. Geosynthetics may be more appropriate for some site-specific circumstances due to the nature, availability or practicality of using clay materials, the nature of the waste or climatic conditions. A cap including geosynthetics may be required to safeguard the protected environmental values of surface water and groundwater at sites with a high potential for leachate generation, sensitive values of surface water or groundwater or unfavourable ground conditions.

Geosynthetics used in a cap may also include materials for collection of water seepage or landfill gas, to control migration of fines, for erosion protection and for geotechnical reinforcement. This section considers the use of geosynthetics as a barrier system only.

Geosynthetics used as part of the barrier system may include:

- geomembranes in conjunction with a compacted clay liner (composite liner)
- a geosynthetic clay liner (GCL)
- a geomembrane in conjunction with a GCL.

## 10.1 Objectives

The objectives of using geosynthetic liners in capping systems for landfill facilities are to provide an equivalent or better level of environmental protection than the minimum requirements for capping systems set by the EPA. Based on a risk assessment, the conditions on a site may require an enhanced level of protection to manage environmental risks; composite liners may provide enhanced environmental protection.

## 10.2 Required outcomes

The required outcomes for use of geosynthetics in a cap liner are as follows:

- The performance of capping systems that incorporate geosynthetics must be equivalent or better than that for a capping system that incorporates a compacted clay liner as an engineered barrier layer, as outlined in Section 9: 'Capping systems'. Demonstration of equivalence should be in terms of risk to the environment (see Section 14 for more information on developing alternative measures).
- Seepage through the cap must be no greater than seepage through the base liner of the landfill.
- Penetrations for landfill gas infrastructure or other penetrations through the liner should be avoided where possible. Penetrations must be designed and constructed so that the liner integrity is maintained.
- The long-term factor of safety against slope instability must be $\geq 1.5$.

- The design life of the liner system must be at least 100 years.

## 10.3 Considerations related to geosynthetic liners

The inclusion of geosynthetic liners in a cap must consider the following items (discussion of further details to follow):

- appropriate design of the cap system, to provide the required level of environmental protection
- general construction considerations of using specialist materials
- durability of the materials
- secondary risks once the system has been installed.

### 10.3.1 Design considerations

The design of a geosynthetic liner within a capping system must include the following considerations:

- the stability of the cap when materials are in contact with a geosynthetic liner, specifically
    - geosynthetic liners generally present a layer with a low friction coefficient, i.e. the interface friction is very low, resulting in a preferential sliding plane. Where appropriate, laboratory testing of geosynthetics in conjunction with the proposed construction materials should be considered to determine the interface friction over the likely confining stress range
    - pressure from landfill gas may build up under the liner due to the very low permeability of geosynthetic liners
    - perched water may accumulate over the geosynthetic liner from infiltration through the cover soils of the cap
- stresses and strains resulting from differential settlement of the underlying waste
- seepage through the liner—this is a primary design consideration and is related to the materials selected and their thicknesses, seepage management, installation control and geometry of the cap. Measures to reduce seepage include
    - a composite rather than a single liner
    - lower permeability of the underlying layers
    - a thicker rather than thinner liner
    - a low hydraulic head over the liner
- control of landfill gas in accordance with EPA guidelines—this may require consideration of gas collection or pressure relief underneath the geosynthetic layer
- effects and risks related to installation of the liner—traffic over geosynthetic liners should generally be limited, and the impact of construction activities must be considered in the design to limit defects in the liner that would result in increased seepage through the system
- the impact of the weather, plants, animals and humans on the geosynthetic liner
- special details such as penetrations, joins to other materials, staging of works, anchorage, edge effects around the perimeter of the cap and effects of settlement of waste on the cap.

### 10.3.2 Construction considerations

The construction of the geosynthetic liner and the underlying and overlying materials must be carried out in accordance with an effective quality control and quality assurance program (refer to Attachment 4: 'CQA minimum requirements'). Poor installation can neutralise the potential benefits of a geosynthetic liner system.

Construction must at least consider the following points:

- good subgrade preparation to provide a sound and stable base for liner construction
- the quality of the geosynthetic liner delivered to site
- the quality of joins
- the risk of damage during handling, storage and installation, including that due to weather conditions, e.g. wind, rainfall and temperature
- provision of intimate contact between the geosynthetic and underlying materials where appropriate, including prevention of wrinkles in the geosynthetic
- construction staging that considers timely placement of materials that act as protection and surcharge over the geosynthetic
- the risk of subsequent damage from other construction activities, such as placement of materials over the geosynthetic liner.

### 10.3.3 Durability considerations

Durability issues are related to the environment of the geosynthetic liner. The durability considerations of GCLs and geomembranes are different.

Geomembrane considerations must include the:

- effect of vapours from the underlying waste
- consequence of exposure to ultraviolet rays
- ambient temperature around the liner.

GCL considerations must include the:

- risk of degradation of reinforcement fibres
- shrink swell of bentonite.

### 10.3.4 Secondary risks

Secondary risks are the effects of events after completion of the cap that may have an impact on the effectiveness of the system, including potential deformations and stresses on the liner system and risks related to the proposed after-use of the capped area. The design must consider these risks and must include measures to protect the integrity of the geosynthetic components and the overall capping system. For example, thicker cover soils may be required underlying access roads to provide acceptable protection to the liner system.

Secondary risks may include, but may not be limited to:

- building foundations
- superimposed loads from soils, vehicles, plant or equipment
- stormwater management
- irrigation

- possible penetration of the geosynthetic materials
- vegetation type, size and root structure.

## 10.4 Suggested measures

### 10.4.1 Acceptable systems

Liner systems that incorporate geosynthetics and are considered to be acceptable for use as a barrier layer in a landfill cap include:

- a geosynthetic clay liner (GCL) that may need to be underlain by a compacted clay liner or engineered layer
- a geomembrane liner underlain by a GCL or a compacted clay liner.

The geosynthetic cap liner system must be considered on a case-by-case basis. However, reinforced GCL and reinforced and unreinforced geomembranes are generally considered as appropriate geosynthetic liners for inclusion in a cap. Acceptable materials for geosynthetic liners include:

- GCL manufactured from polyethylene, polypropylene or polyester geotextile or geomembrane substrate and either sodium bentonite or calcium bentonite filling
- polyethylene geomembrane
- polypropylene geomembrane
- PVC geomembrane
- synthetic rubber geomembrane
- ethylene alloy geomembrane.

### 10.4.2 Minimum requirements

The geosynthetic liner system in the cap must be designed by a person with demonstrated understanding of and experience in the design and installation of the proposed geosynthetics, and the geotechnical considerations related to capping of landfills. The installation of the geosynthetic liner must be carried out in accordance with an effective construction quality assurance (CQA) system (refer to Attachment 4, 'CQA minimum requirements'), as developed in consultation with the EPA prior to commencement of construction. The EPA approved CQA plan may only be varied in consultation with the EPA.

Based on the materials discussed in Section10.4.1 and installation requirements above, the parameters shown in Tables 8 and 9 are considered minimum requirements for geosynthetic liners in caps.

### *Geosynthetic clay liners (GCLs)*

**Table 8 Minimum requirements for geosynthetic clay liners (GCLs) in landfill caps**

| **Dry thickness of GCL*** | **≥ 7 mm** |
|---|---|
| Minimum overall thickness of protection layer | ≥ 700 mm for Type SB+ and MB- sites<br>≥ 900 mm for Type MB+ and L sites |

*measured at a moisture content of less than 10% by weight

The GCL should include a layer of geotextiles over the top and bottom of the bentonite. The GCL should be reinforced, which means the top and bottom geotextiles are linked to provide tensile capacity across the bentonite layer in the GCL. The tensile strength of the linking is a design parameter for the GCL, but for installation purposes should be greater than a peel force of 150 N/m.

In addition, the following minimum requirements must be satisfied:

- the proposed join system must satisfy the basis of the cap design (strain and transmissivity)
- the particle size above or below the GCL must be less than 20 mm in any direction.

### *Geomembrane*

**Table 9 Minimum requirements for geomembrane liners in landfill caps**

| **Thickness of geomembrane** | **≥ 0.70 mm, subject to material type** |
|---|---|
| Strain before rupture or break | > 200% |
| Cover thickness to final surface of cap | ≥ 700 mm |

In addition, the following minimum requirements must be satisfied:

- joins must be permanently bonded, taking into consideration the geomembrane type, e.g. heat bonding for HDPE geomembranes
- the geomembrane must be installed in intimate contact with the underlying layer.

In addition to the above criteria, Tables C1 to C5 in Attachment 6 present minimum properties for various commonly used geosynthetic liner materials (high density polyethylene (HDPE), linear low density polyethylene (LLDPE), polypropylene, PVC and GCL). These properties should not replace design of the liner but are provided as a guide related to survivability during installation and joining.

## 10.4.3 Suggested liner systems

This section presents three options as suggested measures for capping systems that incorporate geosynthetics.

The cover thickness over the top of the liner must be greater than 0.7 m for Type SB+ and MB- sites and 0.9 m for Type MB+ and L sites, in line with the landfill capping guideline and design requirements for liner protection.

*Geomembrane and GCL composite liner*

This liner comprises, from the top of the cap downwards:

- 100 mm topsoil
- a minimum of 600 mm subsoil for Type SB+ and MB- sites and 800 mm for Type MB+ and L sites
- subsoil drainage measures*
- 350 g/m2 cushion of non-woven geotextile**
- 1.0 mm thick geomembrane
- 7 mm thick reinforced GCL
- system to mitigate build-up of pressure under geosynthetics from landfill gas
- cover soil over waste
- waste.

*Geomembrane and compacted clay liner*

This liner comprises, from the top of the cap downwards:

- 100 mm topsoil
- a minimum of 600 mm subsoil for Type SB+ and MB- sites and 800 mm for Type MB+ and L sites
- subsoil drainage measures*
- 350 g/m2 cushion of non-woven geotextile**
- 1.0 mm thick geomembrane
- 500 mm thick compacted clay liner placed in a minimum of three layers
- system to mitigate build-up of pressure under geosynthetics from landfill gas
- cover soil over waste
- waste.

*Geosynthetic clay liner (GCL)*

This liner comprises, from the top of the cap downwards:

- 100 mm topsoil
- a minimum of 600 mm subsoil for Type SB+ and MB- sites and 800 mm for Type MB+ and L sites
- subsoil drainage measures*
- 7 mm thick reinforced GCL
- 200 mm engineered subgrade layer
- system to mitigate build-up of pressure under geosynthetics from landfill gas
- cover soil over waste
- waste.

*Notes on suggested liner systems*

* Design of subsurface drainage measures will need to consider the cap soil types, vegetation, climatic conditions, surface slopes (grade and length), geotechnical stability, stormwater control systems, post-closure use and activities (for example, irrigation, access and maintenance) and control of the drainage water. Build-up of moisture within poorly drained cap soils can have an impact on geotechnical stability, vegetation growth and trafficability, and may increase infiltration through the liner and subsequent leachate generation.

Subsurface drainage must be considered carefully for Type SB+, MB+ and L sites. Risks may be managed at some sites by careful design of slopes and choice of cap soils and vegetation. Subsoil drainage may comprise a series of subsurface interception strip drains. Some sites may require a blanket subsurface drainage system comprising a geosynthetic drainage layer or use of pipes laid in a 200 mm thickness of free-draining granular material.

** This is not required if a geosynthetic drainage layer is used. Design of the cushion geotextile must consider the nature and weight of overlying materials and may therefore differ from the types shown here.

*** Details of landfill classifications (Type SB+, MB-, MB+ or L) are presented in Section 2.2 of this guideline.

# 11 CONSTRUCTION QUALITY ASSURANCE FOR LANDFILL FACILITIES

The development and implementation of a construction quality assurance (CQA) plan provides a means of managing quality during construction and demonstrating to the project stakeholders (owner, contractors, consultants, regulator, the general public) that the construction complies with the landfill design.

## 11.1 Objective

The objective of the CQA plan is to ensure that the materials used, construction methods and completed works comply with the landfill design.

## 11.2 Required outcomes

The required outcomes of the CQA plan include the following:

- development of a CQA plan prior to the start of construction that includes a program of survey, inspection, monitoring, testing, corrective action, documentation and reporting to assess compliance with the design documentation
- implementation of the CQA plan to demonstrate to the EPA and other project stakeholders that the construction complies with the requirements of the landfill design
- obtaining a statement from an independent organisation that the subgrade preparation, lining and leachate collection systems and sumps comply with the project documentation (specification and drawings)
- submission of the 'as-constructed report' for each landfill cell or construction stage.

## 11.3 Suggested measures

The following measures are suggested for achieving the objectives and required outcomes of the CQA plan.

The CQA plan should include a description of the project together with details of the program of survey, inspection, monitoring, testing, corrective action and reporting to assess compliance with the design. This should include the design and specification requirements, CQA scope, timing, hold points, responsibility, documentation and reporting for each element of the plan. The plan should also clearly identify roles and responsibilities of the construction team and detail qualifications and experience, where required.

The plan should include provisions for maintaining the integrity of completed portions of the works and consider issues such as site access and weather conditions.

### 11.3.1 Roles, responsibilities and communication lines

The plan should define clear roles, responsibilities and communication lines for implementation of the plan and for contact with the EPA.

A specific person or organisation must be responsible for the overall implementation of the plan.

### 11.3.2 EPA contact

The plan must include notification of the EPA to provide the opportunity to monitor and inspect elements of the construction. Notification is required at least two weeks prior to commencement of the key elements of the works, including set out, subgrade preparation and construction of the liner and leachate collection systems.

The EPA must be notified if there are changes to site conditions compared with those designed and approved. Similarly, EPA notification in advance is required for proposed changes to agreements between the EPA and the landfill stakeholders.

### 11.3.3 Set-out and survey control

Set-out and survey control of the works should include the elevation reference benchmark and system (Australian Height Datum—AHD), layout plan, base elevation, grades, layer thicknesses, total thickness of elements and the as-built details. It will also need to consider details at the interface between cells and where the leachate drainage layer enters the leachate sump.

### 11.3.4 Subgrade preparation and clay liner construction

CQA of the subgrade preparation and clay liner construction shall include inspection and testing by an independent geotechnical testing authority (GTA) to Level 1 engagement as outlined in Appendix B of Australian Standard *AS 3798-1996 Guidelines on earthworks for commercial and residential developments*.

This includes inspection and testing of materials and the moisture conditioning and compaction process to assess the acceptability and uniformity of materials and workmanship and maintenance of the integrity of completed portions of the works.

Testing includes compliance testing of materials (for example, particle size distribution and Atterberg Limits), field density testing (*AS 1289. 5.8.1*) and reference compaction testing (*AS 1289. 5.1.1* or *AS 1289. 5.7.1*). *AS 3798* provides guidance on the frequency of field density and compaction testing. The test locations and frequency should take into account the size and geometry of the works and if certain aspects require specific attention (for example, protrusions, connections, sumps and so on). Typically, field density and reference compaction testing should be carried out at a frequency of one test per 1,000 $m^2$/layer with additional tests being carried out in areas of specific attention.

Proof-rolling of the prepared subgrade should be conducted to assess the presence of weak or compressible zones that may require improvement.

Inspection should be conducted of the method of bonding between layers of the clay liner. This should take into consideration surface and moisture conditions at the interface between layers.

Items for potential corrective action include, but are not limited to, non-uniformity, non-complying materials (for example, inclusions of oversized material or organic matter), moisture condition or compaction outside the specified criteria, inadequate bonding between layers and non-complying geometry or thickness.

The GTA should progressively provide feedback to the project stakeholders, including the EPA, on the results of the inspection and testing program. On completion of the inspection and testing program, the GTA should provide a report of the program of inspection and testing and a statement of the compliance of the clay liner construction with the project documentation.

Testing should be conducted to assess whether the hydraulic conductivity of the completed liner complies with the design. This can be done by laboratory testing of undisturbed samples of the liner in accordance with *AS 1289. 6.7.1–1999* or by field testing. The minimum testing requirements are dependent on the scale of the construction works. For example, for typical cell size of 100 m by 100 m a minimum of three tests per cell is required. The sample size and test method should consider the particle size distribution of the materials tested.

### 11.3.5 Geosynthetic materials

CQA of supply and installation of geosynthetic materials will need to consider the following:

- requirement for full-time supervision of the installation of geosynthetic materials
- material properties and manufacturing quality assurance
- inspection of materials when delivered to the site
- storage and handling procedures
- preparation of the ground surface prior to installation, to minimise the risk of damage to the geosynthetic. This may include, but not be limited to, geometry, smoothness, the presence of sharp objects, density and moisture condition
- the presence of defects
- set out of panels
- anchoring points
- the connections between panels or elements
- connection of areas that have undergone sampling or repair with the main works
- the interface with underlying or overlying materials
- methods to protect the integrity of completed portions of the works.

Consideration may need to be given to quality assurance guidelines of the geosynthetic manufacturer.

### 11.3.6 Leachate collection system and sump

CQA of the leachate drainage layer and sump as part of the leachate collection system will need to consider the following:

- grades to and along drainage lines
- the manufacture, type, delivery, storage, handling, layout, bedding, connection and integrity of leachate collection pipes

- the sump geometry and connection to the leachate drainage layer
- the thickness of granular drainage materials
- the particle size distribution, composition and placement of granular drainage materials to comply with the design requirements for durability and hydraulic conductivity
- the integrity of the underlying liner system.

### 11.3.7 CQA report

A CQA report must be prepared that demonstrates to the EPA and other project stakeholders that the construction complies with the requirements of the landfill design. It shall include the results of the program of survey, inspection, as-constructed drawings, monitoring, testing and corrective actions.

# 12 CLOSURE AND POST-CLOSURE PLANS

*Note: This section replaces the EPA Guideline 194/03 (September 2003) 'Closure and postclosure plans for major landfills'. The aim of this section is to provide direction and consistency for closure and post-closure care of landfill facilities.*

This section considers important issues arising from the EPA's experience with preparation and implementation of closure plans by landfill operators. Suggested measures within this section also consider the classification of landfill types (based on waste disposal and site conditions), which are outlined in Section 2.2.

The post-closure aspects in this guideline apply for all future, operating and closed landfill facilities.

The closure aspects in this guideline apply to:

- future landfill cells at all facilities
- current landfill cells that do not have a closure plan approved by the EPA
- closed sites where the EPA considers that the closure or post-closure management is, or is likely to be, inadequate to guard against pollution.

## 12.1 Objectives

The objectives of closure and post-closure plans for landfill facilities are to:

- provide long-term protection of human health and the environment
- minimise the generation and uncontrolled emissions of leachate and landfill gas, which may have adverse impacts on human health or the environment
- promote responsible land management and ensure that site closure and post-closure management are compatible with an appropriate post-closure use of the site
- manage hazards and amenity issues
- promote progressive closure of landfill cells within operating landfill sites
- limit the risk of post-closure maintenance and monitoring beyond the timelines included in this guideline
- improve systems for monitoring, review and maintenance during post-closure management
- maintain environmental protection measures and monitoring systems until it is demonstrated that the landfill no longer presents a risk to human health or the environment.

## 12.2 Required outcomes

The required outcomes of closure and post-closure plans for landfill facilities are to:

- prepare a post-closure plan
  - as part of the design and approval process for new landfills and new landfill cells
  - within 18 months of the issue of this guideline for operating and closed landfills
- prepare a closure plan for future landfill cells at all facilities; current landfill cells that do not have a closure plan approved by the EPA; or closed sites where the EPA considers that the closure or post-closure management is, or is likely to be, inadequate to guard against pollution
- review and update the closure and post-closure plan at every landfill at intervals of not greater than two years. The review must consider the results of monitoring and changes in site conditions, environmental management measures and regulatory requirements
- design and install a capping system in accordance with the measures outlined in Section 9: 'Capping systems'. This must provide a stable cover over the waste, safeguard the protected environmental values of surface water and groundwater, and prevent and manage potential hazards associated with landfill gas
- install the landfill cap within 12 months of cell closure
- manage landfill gas in accordance with the measures outlined in Section 8: 'Management strategies for landfill gas and air quality'
- implement the plans including a program of inspections, monitoring, review and continuous improvement
- plan and implement a program of post-closure management until it is demonstrated that the landfill no longer presents a risk to the environment or human health.

## 12.3 Suggested measures for closure plans

### 12.3.1 Plan preparation and approval

The plan should be prepared in accordance with the principles of continuous improvement outlined in *AS/NZS ISO 14001:1996 Environmental management systems—specification with guidance for use*, including the cycle of policy, planning, implementation, checking, corrective action and management review.

Plans will require EPA approval before implementation and must be reviewed by the licensee at least every two years, as outlined in Section 12.2.

Planning for closure should consider landfill operational issues in the landfill environment management plan (LEMP) for the site. These include, but are not limited to, landfill cell development, waste placement and compaction, earthworks materials, and measures to manage waters and landfill gas. Progressive closure of landfill cells must be carried out within 12 months of the completion of waste disposal in the cell, unless otherwise approved by the EPA.

The plan must include a program for implementation (as a Gantt chart or similar format) and a program of quality assurance and reporting to the EPA.

Landfill operators should make funding provision during landfill operation to cover costs for closure and post-closure management.

### 12.3.2 Post-closure use

The proposed post-closure use of the site must be outlined in the closure plan and must consider:

- the landfill location
- surrounding land uses
- consultation with the local community
- relevant regulatory and planning authority strategic plans for acceptable land use
- post-closure management measures and infrastructure, e.g. for management of water issues and landfill gas
- issues related to land use and land contamination.

Common types of post-closure use include:

- rehabilitation of sites with vegetation but with controlled access and limited public access
- public open space
- ongoing use for waste management, e.g. as a waste transfer station, materials resource recovery facility (MRRF) or for processing of green waste.

The EPA discourages the construction of water features over the waste site as part of landfill closure due to the risk of differential settlement, potential water leakage and leachate generation.

Specialised engineering measures must be included if buildings, roads, water features or utilities are proposed, and must consider the risk of differential settlement, ground support and hazards associated with landfill gas.

### 12.3.3 Final shape (landform)

The final landfill shape must be compatible with the surrounding topography and land uses. It must consider the post-closure use of the site, stormwater and erosion control, stability, the capping system, development approval and planning regulations.

The plan must nominate the final height prior to settlement and proposed surface grades or contours. The final contours must consider settlement as the waste decomposes, compresses and consolidates. Steep slopes must be battered with an overall gradient being a maximum of 1 vertical and 3 horizontal, unless an engineering design has been approved to control the long-term stability on steeper batter slopes.

### 12.3.4 Hazards and loss of amenity

The closure plan must consider hazards and amenity issues that include, but may not be limited to, the following:

- site access, security, fencing and signage
- occupational health and safety for workers and visitors to the site
- fire
- dust
- odour
- vermin.

The plan must identify hazards and include management measures for these risks.

### 12.3.5 Capping system

The landfill must be covered by a capping system that provides a long-term separation layer between the waste and the final surface, protects human health and the environment and is compatible with the intended post-closure use.

Design and construction of the capping system must be undertaken in accordance with the measures outlined in Section 9: 'Capping systems'.

### 12.3.6 Stormwater and erosion control

Stormwater management strategies must consider the following:

- management of surface water on site and control and monitoring of off-site stormwater discharge
- erosion and sediment control along drainage lines, disturbed areas and soil stockpiles. This includes stormwater flow control, vegetation use, installation of detention ponds, minimal land disturbance and other temporary and permanent erosion protection measures.

Management strategies and design criteria for storm events should consider potential receptors of stormwater and the consequences of uncontrolled discharge, based on site-specific circumstances. Typical design criteria include, for example, the 1 in 10 year or 1 in 20 year recurrence interval storm event for design of drainage features; and the 1 in 100 year recurrence interval storm event to assess the risk of major breakdown events such as failure of detention ponds, or flooding of the landfill area or sensitive facilities or receptors.

Detention ponds should incorporate erosion and flow control measures including erosion resistant banks, baffles and spillways.

Guidance on stormwater management is presented in the *Stormwater pollution prevention code of practice for the building and construction industry (EPA 1999)* and the *Stormwater pollution prevention code of practice for local, state and federal government (EPA 1997).*

### 12.3.7 Landfill gas management

The closure plan must consider management of landfill gas in accordance with the measure outlined in Section 8: 'Management strategies for landfill gas and air quality.

### 12.3.8 Leachate management

The closure plan and capping design must include measures to limit the generation of leachate. It should also consider collection, storage and treatment systems to manage the leachate that is generated. These systems must be designed and operated to prevent odour and pollution of surface water and groundwater, and minimise human contact with the leachate.

Further guidance on leachate management is presented in Section 6: 'Leachate containment and management systems'.

### 12.3.9 Termination of waste disposal

The plan must consider measures to provide sufficient notice to users of the site that the landfill will be closing and will no longer accept waste. Measures will also be required to prevent post-closure waste disposal or illegal dumping.

## 12.4 Suggested measures for post-closure management

Post-closure management must be undertaken until there is sufficient evidence to demonstrate to the EPA that the site is stable and poses only acceptable risks.

Post-closure management must include:

- management of systems to control landfill gas migration or emissions
- management of leachate control systems and remediation of groundwater if it is contaminated
- monitoring and maintenance of environmental protection measures
- monitoring of stormwater, groundwater, leachate and landfill gas.

The minimum duration for post-closure management from closure of the last cell is 25 years. This length of time may be shorter if there is sufficient evidence to demonstrate to the EPA that the site is stable and poses only acceptable risks. Conversely, a longer duration may be required if the site poses unacceptable environmental risks.

Preparation of the inspection, monitoring and maintenance program for post-closure management must consider:

- site characteristics gathered from: available information; site personnel; and site inspection, investigation and monitoring, including
  - waste placement (e.g. extent, time, volume and nature)
  - site conditions (e.g. geometry and topography, weather, waters, geology, surrounding land, capping system, integrity of the final cover and vegetation, landfill gas risks and leachate)
  - potential future changes.
- hazards that have potential on-site or off-site impacts on the environment, human health, the community or property
- options for corrective action as required.

The inspection and monitoring program should build on the monitoring program carried out during landfill operation (if appropriate) and include the following:

- monitoring of groundwater, surface water, landfill gas and leachate

- the timing and nature of, and response to, community complaints
- inspection of the condition, integrity and performance of the following items:
  a. landfill cap, including differential settlement, cracks, leachate springs, soil erosion, stability and vegetation
  b. stormwater control system
  c. site security, access control and fire mitigation measures
  d. infrastructure and buildings
  e. access roads
  f. leachate management systems
  g. landfill gas management system.

  The frequency of inspection and type of maintenance measures undertaken should be based on the nature of the item, the site conditions and the results of the monitoring. The frequency should be clearly stated and reviewed on at least an annual basis. A starting point for the frequency of items a) to e) may be at least every two months, and at least two days before extreme weather events as well as after these events. Extreme weather events are those that pose a high risk of damage to environmental protection measures and may include high and/or intense wind events. The frequency for items f) and g) should be based on the system requirements and monitoring results
- monitoring of amenity issues such as noise, dust, odour and vermin
- a process to implement maintenance actions resulting from the inspection and monitoring program
- reporting and review of the inspection and monitoring program
- reporting to the EPA on at least an annual basis.

# 13 LANDFILL ENVIRONMENT MANAGEMENT PLAN (LEMP)

This section outlines the requirement for a landfill environment management plan as part of the development application for new landfill sites, and as required by the EPA licence for existing landfill sites.

A landfill environment management plan (LEMP) must be prepared by proponents and licensees to ensure that the commitments in an environmental impact statement (EIS) and related documents, the development application, any conditions of a planning consent and the EPA licence are implemented.

### 13.1.1 New landfill sites

For new landfill sites, as part of the development application process, a development LEMP is required detailing site information, the concept design for the site (including the detailed design of works associated with the initial stage), the nature of operations (including related activities such as waste treatment, recycling and composting) and the ongoing monitoring programs.

The stages associated with the LEMP, between development application and EPA licensing, are summarised in figure 5.

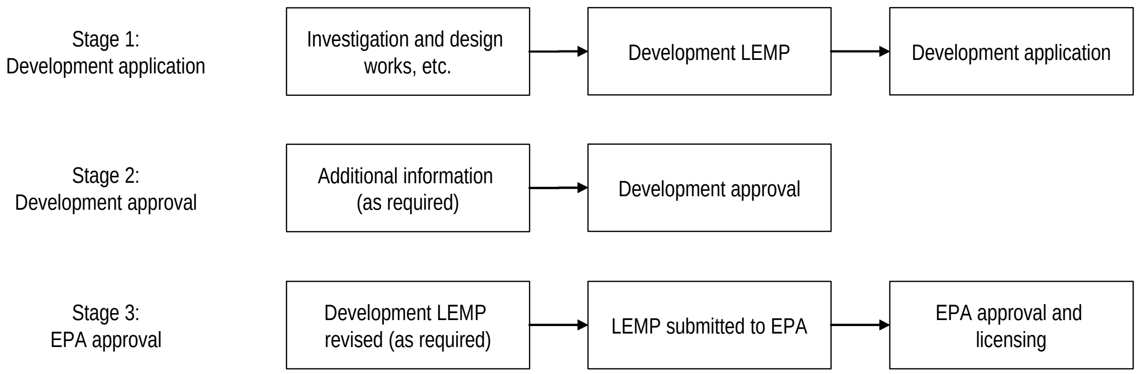



**Figure 5 – Stages associated with a LEMP**

### 13.1.2 Existing landfill sites and sites with development approval

The LEMP serves as a technical reference document, design record, and general management and monitoring plan for the development and ongoing operation of a landfill site. If other activities such as waste treatment, recycling and composting are undertaken on site, all relevant details must be included in the LEMP and follow the LEMP structure.

For existing landfill sites and sites with development approval, review and updating of the LEMP is an EPA licence requirement. At this stage, the LEMP provides the framework for the management and mitigation of environmental impacts during construction, operation and closure of the landfill, as well as for the post-closure period.

## 13.2 Structural framework for the LEMP

It is recommended to structure the LEMP as a series of documents rather than a single document. It will detail the need for continual provision of information by the licensee to the EPA as part of the ongoing approval process. As such, the need for a database system that is kept and maintained by the licensee as an information register becomes a critical component in the structure of a LEMP.

The structural framework for the LEMP is demonstrated in Figure 6 and the components are detailed further in Section 13.2.3: 'Content of the LEMP'.

This framework applies to new landfill sites, existing sites and sites with development approval.

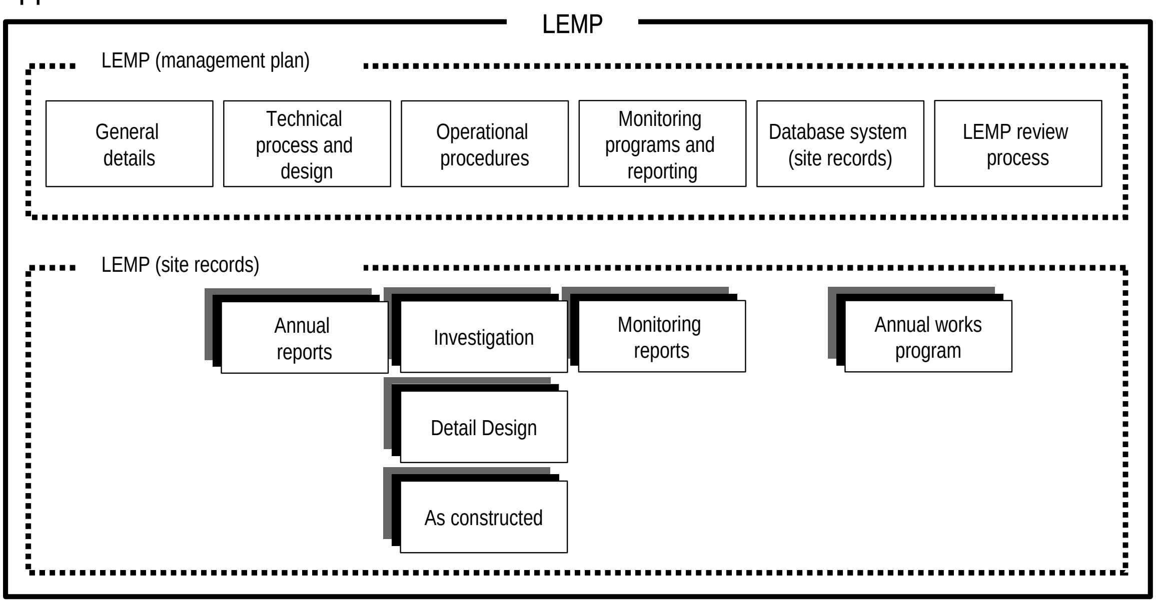



**Figure 6 – Structural framework for a LEMP**

### 13.2.1 New landfill sites

For new landfill sites the development LEMP will consist of the management plan and the site records (see Figure 6).

The management plan contains details of the general site information, operational elements, the concept design for the landfill site (including closure) and routine monitoring components.

The site records contain detail design for the initial stage, together with relevant site investigations to substantiate the adequacy of the concept design. The site records will be referenced in the database system included in the management plan. On receiving development approval, the LEMP will be revised, as necessary, to comply with EPA licence requirements and submitted to the EPA for approval.

### 13.2.2 Existing landfill sites and sites with development approval

For existing landfill sites and sites with development approval, the LEMP will consist of the management plan and the site records (see Figure 6).

The management plan details the general site information, operational elements, the concept design for the landfill site (including closure) and routine monitoring components.

The management plan will be based on all available site information. It must clearly state the need for further investigations to confirm the adequacy of both the concept design and the monitoring program, and that the ongoing development of the landfill site will be undertaken as a series of construction works.

The management plan will also incorporate a process for review based on the outcomes of the regular reporting requirements and investigations, for example, extending the monitoring program as the landfill site is developed.

The site records contain the documentation of detail design for the current stage, together with relevant existing documents, for example, annual reports and monitoring reports.

The investigation projects and construction works will be associated with specific deliverables and timeframes. The information shall be included in the site records as an annual works program.

Each of the documents to be included in the site records will be referenced in the database system within the management plan.

### 13.2.3 Content of the LEMP

The management plan, which forms a key part of the LEMP, should be considered as having six components:

- general details
- technical process and design, including closure and post-closure plan
- operational procedures
- monitoring programs and reporting
- database system (reference system for site records)
- LEMP review process.

These components will generally be subject to revision, at differing intervals, as a result of the key management processes remaining relatively constant throughout the life of the landfill site. For example, the requirements for regular operational reports and environmental monitoring are relatively constant. In contrast, the focus of the landfill development may change to reflect increased knowledge based on site investigations, or changes in function, technology or regulation; or in response to non-conformance issues.

Sections 13.2.4 to 13.2.9 provide a description of typical sections of the management plan to provide a measure of direction and consistency in the approach that should be taken in preparing the plan. It should be noted that the items included under the separate components of the management plan are not mutually exclusive, and cross-referencing between the components should be considered.

### 13.2.4 General details

The general details component of the LEMP should provide a general description of the landfill site and include the following sections as a minimum:

- legislative requirements—legislation applicable to preparation of the LEMP and operation of the site including summary of standards and guidelines to be adopted
- planning information—Section and Hundred (including Certificate of Title), ownership and tenure details, council area, zoning and adjacent zoning and buffer distances (including to nearest buildings and residences)
- development approval—reference and related documents
- location and site layout plan
- site overview—infrastructure details, hours of operation (public and private) and security provision
- nature of operation and capacity—waste streams, filling rates, lifespan and related activities on site
- summary of site conditions—climate, topography, geology, hydrogeology, groundwater and surface water
- proposed end use.

### 13.2.5 Technical process and design

The technical process and design component of the LEMP should include the following sections as a minimum:

- site investigation information—geology, hydrogeology, groundwater, surface water and landfill gas
- reference to development approval, EPA licence requirements and relevant EPA guidelines
- concept design for landfill site—outline performance criteria for liner and leachate management system, interface between cells (as appropriate), capping and final landform, landfill gas management and stormwater management
- landfill stages—include reference to site records for the investigations, detail design and as-constructed details that are applicable to each development stage
- associated works—erosion control measures, and so on.

### 13.2.6 Operational procedures

The operational procedures component of the LEMP should detail the environmental management systems (considering *AS/NZS ISO 14001:1996 Environmental management systems—specification with guidance for use*) and best practice procedures that will be adopted at the site, including the following sections as a minimum:

- management structure—roles and responsibilities
- reporting and records—protocols and requirements, including recording of waste types and tonnages, environmental monitoring reporting requirements and non-conformance procedures
- training—procedures for on-site staff and contractors for environmental and OHS&W compliance

- reference to development approval, EPA licence requirements and relevant EPA guidelines
- waste management procedure—operational filling process, including compaction methods, management of specific wastes and retrieval of unauthorised wastes
- recycle and/or reuse of materials—procedures for diversion and/or separation of recyclable and reusable materials, including stockpile and associated environmental control measures
- site materials and equipment—procedures for handling and storing materials associated with site operations, including site machinery, equipment and maintenance
- traffic control—entry and exit to landfill including internal access routes for the public, contractors and on-site staff
- environmental controls—procedures for control of litter, dust, mud, odour, noise, vermin, birds, weeds and so on
- emergency response—response and action plan for identified emergency scenarios, based on risk assessment approach, including fire prevention and control.

### 13.2.7 Monitoring programs and reporting

The monitoring programs and reporting component of the LEMP should include sections addressing the following issues as a minimum:

- groundwater
- surface water
- leachate
- landfill gas (LFG)
- air quality and noise—dust, mud, litter, noise and odour
- vermin, birds, weeds etc.

The monitoring programs should provide the following details as a minimum:

- locations—site plan and details
- monitoring interval and duration (cross-reference to site records—annual works program)
- sampling protocols including quality control, referring to relevant guidelines and/or standards (as appropriate)
- reference to development approval, EPA licence requirements and relevant EPA guidelines
- compliance criteria, including framework for the implementation of recommendations resulting from monitoring events
- procedures for non-compliance (cross-reference to operational procedures—reporting and records)
- reporting—internally and externally (cross-reference to operational procedures—reporting and records).

### 13.2.8 Database system (site records)

The database system is a critical component of the LEMP, as the management plan will refer to operational records and reports, design information and monitoring reports, which shall become the site records for the landfill site. The site records should be referenced within the management plan on a regular basis, though this may not be necessary on an annual basis.

The format of the database system should facilitate ease of reference to the site records and incorporate a process for identifying superseded documents, and should include the following items as a minimum:

- provision for document identification numbers
- provision for issue dates and authors.

### 13.2.9 LEMP review process

The review period for LEMPs for medium and large landfill sites (MB-, MB+ and L) shall be on an annual basis, unless otherwise specified in the licence.

The review period for LEMPs for small landfill sites (SB- and SB+) shall be every three years or as otherwise specified in the licence.

Given the ongoing record keeping, monitoring and reporting associated with the landfill site, the review of the LEMP should demonstrate that the sufficiency of the operational, design and monitoring systems for the current development stage of the site has been addressed.

The review process should be established to ensure continual improvement in the management and operation of the landfill site, as demonstrated in Figure 7.

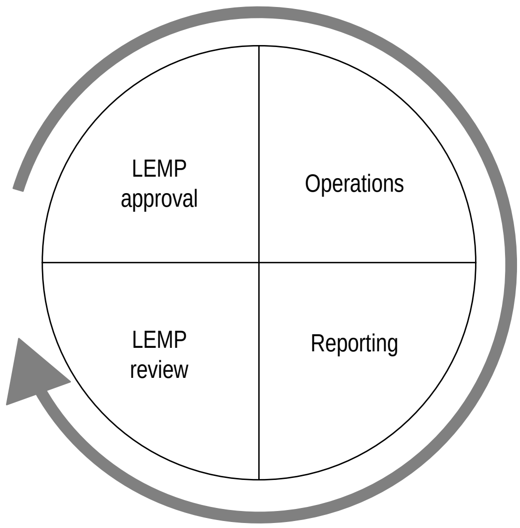



**Figure 7 – Management and operation cycle of a landfill site**

A checklist system, or similar, will be included in the management plan to identify the process to be used in reviewing the LEMP. The checklist system will be used to clearly demonstrate that the site records issued since the previous LEMP review have been considered as part of the review process, to clearly identify actions required and outcomes, if any. An example of the format of a checklist system is provided in Table 10.

**Table 10 Example of the format of a checklist system**

| Review of site records | Management plan | Details | Action taken in LEMP review |
|---|---|---|---|
| Additional information available from current aerial survey and EPA weighbridge returns | General details | Legislative requirements | Update management plan: nature of operation and capacity |
| | | Planning information | |
| | | Development approval | |
| | | Location and site layout plan | |
| | | Site overview | |
| | | Nature of operation and capacity | |
| | | Summary of site conditions | |
| | | End use | |
| Increased site knowledge revised based on outcomes from previous year's groundwater investigations | Technical process and design | Site investigation information | Update management plan: site investigation information |
| | | Reference to relevant EPA Guidelines | |
| | | Concept design for landfill site | |
| | | Landfill stages | |
| | | Associated works | |
| Non-conformance associated with environmental controls and addressed as corrective action | Operational procedures | Management structure | Update management plan: environmental controls |
| | | Reporting and records | |
| | | Training | |
| | | Waste management procedure | |
| | | Recycle/reuse materials | |
| | | Site materials and equipment | |
| | | Traffic control | |
| | | Environmental controls | |
| | | Emergency response | |
| Additional groundwater monitoring wells installed as part of previous year's groundwater investigations | Monitoring programs and reporting | Groundwater | Update management plan: groundwater |
| | | Surface water | |
| | | Leachate | |
| | | LFG | |
| | | Air quality—dust, mud, litter, noise, odour | |
| | | Vermin, birds, weeds etc. | |
| Site records issues to EPA | Database system | | Update management plan: database system |

## 13.3 LEMP review and approval—existing landfill sites and sites with development approval

### 13.3.1 LEMP review

The LEMP review process (for example, a checklist system) will assist in identifying the outcomes from site investigations, operational reporting and/or monitoring programs and so on, for incorporation in the management plan as appropriate. As a result, the outcome of the LEMP review process may be that only specific sections of the management plan may be subject to revision and submission to the EPA for approval.

To assist in the review and update process for the management plan, a site-specific quality assurance (QA) system should be considered, together with the use of a binder format and unique page identification, to allow additions and/or alterations to the component sections as required. The QA system should also extend to the database system used to reference the site records.

### 13.3.2 LEMP approval

In considering the EPA process for assessment and approval of the LEMP subject to a review process, the licensee should be able to demonstrate that the following issues have been addressed, as a minimum but not limited to:

- the management plan that was approved as part of the development approval for the site is valid in terms of current environmental legislative requirements, EPA licence requirements, guidelines and best practice standards
- sufficient information is provided by the licensee for the current detail design stage to allow the EPA to assess that the performance criteria detailed in the management plan will be complied with
- investigation projects and/or construction works to be undertaken in the subsequent year(s) after i) the initial stage of a new landfill, ii) the current stage of an existing landfill or iii)for a landfill with development approval, which will be associated with the annual works program, and identified in sufficient detail and related to realistic timeframes
- the site records submitted to the EPA are referenced in the database system.

## 13.4 Relevant sections in this guideline

The relevant sections of this guideline should be referred to in the preparation of the LEMP. These sections provide guidance for landfill facilities for municipal solid waste and commercial and industrial general waste, in particular:

- screening and siting of landfill facilities (Section 3)
- site layout for landfill facilities (Section 4)
- environmental assessment and water management strategies (Section 5)
- leachate containment and management systems (Section 6)
- the use of geosynthetic materials in base lining systems (Section 7)
- management strategies for landfill gas and air quality (Section 8)
- capping systems (Section 9)
- the use of geosynthetic materials in capping systems (Section 10)
- construction quality assurance for landfill facilities (Section 11)
- closure and post-closure plans (Section 12)
- variations and alternatives to guideline measures (Section 14).

# 14 PROPOSAL OF VARIATIONS OR DEVELOPMENT OF ALTERNATIVES TO GUIDELINE MEASURES

The measures (designs, techniques and methods) contained in guidelines reflect widely accepted practice. Whilst this presents a reference design, variations may be permissible or required in some site-specific circumstances, provided sufficient and appropriate justification can be provided.

The aim of this section is to inform proponents of steps considered necessary by the EPA for the proposal, evaluation and acceptance of variations or alternatives to guideline measures. It is intended to provide an objective, transparent and efficient process to assess variations. The staged approach aims to promote early communication between the parties and efficient use of resources.

Proponents should be aware that while the process outlined in this section may provide useful guidance, it has not been prepared specifically to apply where variations or alternatives are sought to respond to field conditions or problems encountered during construction.

## 14.1 Process overview

The consideration of variations or alternatives can be rationalized to a three step process as shown in Figure 8. Each step in the process is described in more detail in the following sections.

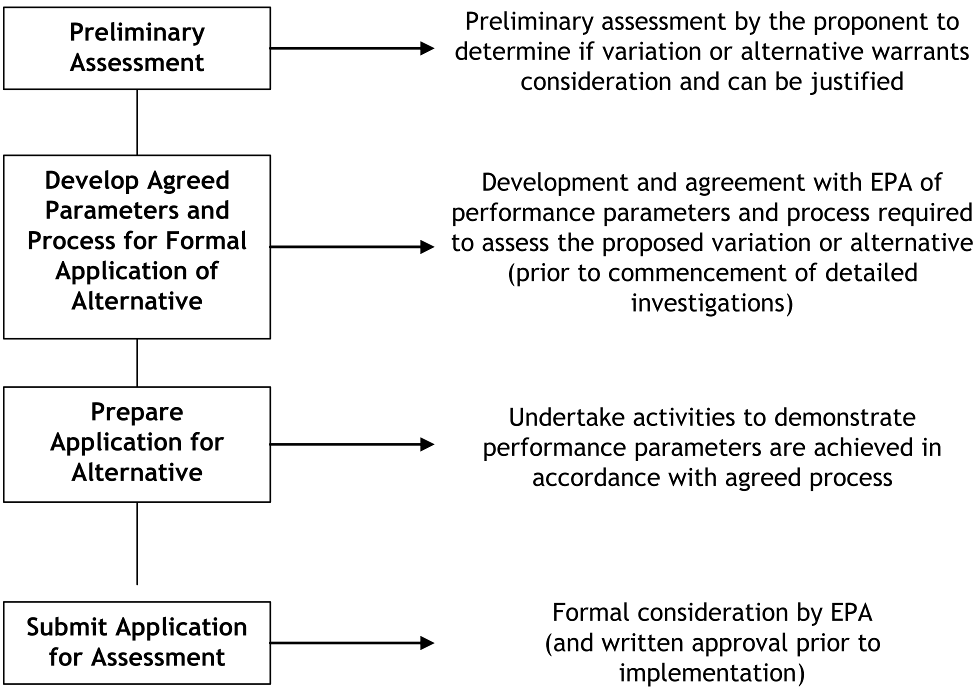



**Figure 8 - Management and operation cycle of a landfill site**

## 14.2 Preliminary Assessment

The proponent shall assess and describe the reason the variation or alternative is preferred. For example:

- substitution of materials, methods or techniques
- continual improvement
- application of best practice, technological change
- practical considerations
- arising from site-specific knowledge, conditions or risks
- reduced risk
- equivalent or better performance
- corrective action arising from a non-conformance
- cost or time saving or other net benefit.

At this stage the proponent shall conduct a preliminary assessment which considers:

- parameters necessary to assess performance of the alternative
- the advantages and disadvantages of the proposal
- risks and consequences of adopting the alternative (compared with the guideline or existing approved approach)
- magnitude of cost and other resource savings
- magnitude (if quantitative) or list (if qualitative) of comparative benefits and/or outcomes
- variations necessary for statutory approvals (planning consents, licence conditions and environmental authorisations or exemptions).

On the basis of this assessment, the proponent shall form a view as to the merit of pursuing the alternative prior to a formal approach to EPA.

## 14.3 Development and agreement of performance parameters and process

It is important to gain agreement with the EPA on performance parameters prior to commencement of alternative measures. Proponents should submit a preliminary assessment to the EPA together with a proposal to provide the following items or undertake the following processes (as shown in Table 11) to the EPA for discussion and agreement prior to commencement.

**Table 11 Process for discussion and agreement prior to commencement of alternative**

| Item | Required | If Yes, describe requirement / scope / objective / outcome |
|---|---|---|
| Performance parameters for comparative evaluation | Y | List (qualitative & quantitative) |
| Cost / benefit assessment | Y/N | |
| Performance assessment | Y/N | |
| Evidence of successful use or experience | Y/N | |
| Literature review | Y/N | |
| Manufacturer data | Y/N | |
| Test data | Y/N | |
| Trial | Y/N | |
| Modelling, for example, method, data, sensitivity analysis | Y/N | |
| Risk assessment | Y | |
| Considerations for proposed implementation of variation or alternative, for example, methodology, documentation, schedule, quality assurance and monitoring | Y/N | |
| Peer review | Y/N | By whom |
| Timeline | Y | Include anticipated first use |
| Variations to statutory approvals required | Y/N | |
| Other as considered necessary | Y/N | |
| Format and content of application | Y | |

The proposal shall clearly define performance requirements and outcomes, and where these are not clear at this time, outline a process proposed to enable an objective assessment.

A process to define performance requirements for any proposal will need to be completed before an assessment will be considered and agreement can be reached.

A detailed timeline and proposal for an appropriately detailed risk assessment is expected in each case.

It may also be necessary for the proponent to apply for a variation to an existing planning consent, and for the EPA to respond to a request for advice from the Planning

Authority in relation to the variation. This process needs to be considered in the proponent's time and work schedule.

The EPA will respond in writing to the proponent's proposal, and either:

- indicate acceptance of the proposal scope as sufficient to enable an application to be made with sufficient detail to enable assessment

or

- provide feedback on areas where the proposal is considered deficient for further consideration by the proponent.

Following consideration of proposals by the EPA, the proposal will be classified broadly as outlined in Table 12.

**Table 12 Process for discussion and agreement prior to commencement of alternative**

| Type of variation | Detail | Timing / cost |
|---|---|---|
| Minor variation | Provision of test or manufacturer data and/or an report by a suitably experienced and qualified person | Least |
| Significant variation | As for minor plus trial, modelling and specific investigation | Moderate |
| Major variation | As for significant plus peer review | Greatest |
| No agreement | Agreement is unable to be reached on necessary investigation scope or required performance parameters for assessment of variation or alternative | Varies |

Peer review and possibly trials are likely to be required for new or innovative alternatives not currently accepted widely as best practice or considered transferable from evidence of successful application or use elsewhere. Where peer review is required, both the EPA and proponent must agree on the organisation(s) or person(s) undertaking the review and commercial arrangements.

With this acceptance, the proponent can commence the full scope of work necessary to produce an application to the EPA for consideration of the variation or alternative.

## 14.4 Prepare application for alternative

The proponent shall conduct the work necessary to prepare the application in accordance with the proposal.

Should the work identify or prompt a change to the scope defined and accepted by the EPA, the proponent shall seek acceptance of the change prior to proceeding with or concluding the work.

## 14.5 Submit application for assessment

Following submission of the application, the EPA will assess the application against the performance requirements and outcomes described in the application. This assessment will provide information and advice for consideration by the EPA in forming its opinion on the application for a variation or alternative.

Implementation of any alterations or variations proposed may only proceed following the receipt of a formal approval by the EPA (and any other relevant authorities).

## 14.6 Examples

### 14.6.1 Proposal to substitute a synthetic drainage layer for an aggregate drainage layer

#### a) Preliminary assessment

The site location makes the supply of suitable drainage aggregate material costly, and commercially available synthetic drainage products appear to be a cost-effective alternative and a comparable or improved performance can reasonably be expected.

An example made available by a supplier of the recent use of their product is provided in this application.

This site's design has already been approved by the EPA for construction using the guideline specification for drainage aggregate.

The development consent for the landfill was reviewed and found not to have been granted with reference to a specific design, which would be varied by the proposal.

#### b) Development and agreement of performance parameters and process

A proposal is submitted to the EPA which outlines the use of the proposed material and covers the following aspects:

- local availability, cost and performance compared with the proposed alternative
- case study details provided by supplier
- material performance characteristics including hydraulic properties
- the opinion of the design engineer that the drainage performance and clogging potential of the product matches or exceeds that of the approved design
- a review by the design engineer to confirm that:
  - the load applied to the layer is within the manufacturer's specification for the approved design
  - the proposal takes into consideration risks, consequences and comparable performance
  - consideration has been given (and proper assessment if applicable) to the overall design and performance of the facility.

The proposal also identified required changes and committed to provide:

- revised design drawings to show the substitution
- revised specification and CQA plan amended to reflect the use of the product, the supplier's installation requirements and inspection of joins.

The EPA considers the proposal and issues a response that confirms that the proposal is accepted in principle by the EPA, and may be adopted following acceptance by the EPA of the revised documentation.

#### c) Preparation of application

The proponent prepares revised design drawings, specification and a CQA plan with reference to the original proposal submitted, and formally submits these to the EPA.

**d) Application for assessment**

The EPA will assess the application and advise the proponent of the outcome of that assessment in writing.

The proponent must not commence the implementation of any variations unless they have received written approval from the EPA.

### 14.6.2 Proposal for an alternative base liner profile

**a) Preliminary assessment**

A proponent wishes to adopt a composite base liner profile that uses geosynthetic materials. This is because acceptable clay liner materials are in limited supply and are costly.

The site classification is MB+. An existing approval exists utilising a 1000 mm thick clay liner in accordance with the guidelines, and this has previously been assessed as acceptable at the site.

Information both locally and from interstate and overseas indicates that composite liner systems have been successfully implemented at landfill sites to manage the risk of adverse environmental impact from leachate and landfill gas.

The EPA guidelines include an option to consider the use of geosynthetic materials in landfill liner systems.

The development consent for the landfill was reviewed and found not to have been granted with reference to a specific design which would be varied by the proposal.

**b) Development and agreement of performance parameters and process**

A proposal is submitted to the EPA which outlines the following aspects:

- limited availability of suitable clay liner materials for the project
- summary of the environmental assessment at the site
- the concept design profile of the leachate collection system and liner including a separation geotextile, 300 mm leachate drainage aggregate, drainage pipework, cushion geotextile and 2 mm thick HDPE geomembrane, overlying a 300 mm compacted clay liner
- preliminary opinion that the alternative composite liner profile has a reduced risk of leachate leakage compared with a 1000 mm thick compacted clay liner
- proposed scope of assessment including computer modelling to assess the relative performance of the proposed composite liner compared with the 1000 mm thick compacted clay liner. The assessment considers advective flow and diffusion of potential contaminants through the liner and unsaturated zone. The modelling would assess the sensitivity of model assumptions and input parameters, for example, leachate composition, leachate head over the liner (0.3 m and 3 m), timing (20 years and 100 years), concentrations of parameters at a distance of 4 m and 10 m below the base of the liner and properties of the compacted clay liner and materials in the unsaturated zone beneath the liner

- identification of the scope of work for detailed design and documentation proposed for the composite liner system, including consideration of geotechnical stability, waste filling plan, technical specification, drawings and quality assurance
- variations necessary to statutory approvals.

The EPA considers the proposal and issues a response that confirms that the proposal is accepted in principle by the EPA as appropriate to enable it to properly assess the application.

**c) Preparation of application**

The proponent conducts the works and investigations outlined, and prepares a comprehensive report and formally submits this to the EPA.

**d) Application for assessment**

The EPA will assess the application and advise the proponent of the outcome of that assessment in writing. If the alternative liner profile is acceptable to the EPA, the construction drawings and specifications can then be revised and completed by the proponent and submitted to the EPA for assessment. The proponent must not commence the implementation of any variations unless they have received written approval from the EPA.

# 15 REFERENCES AND DEFINITIONS

## 15.1 References

International Organization for Standardisation 1995, ISO 10693:1995 Soil quality—Determination of carbonate content

International Organization for Standardisation 1995, *ISO 10694:1995 Soil quality—Determination of organic and total carbon after dry combustion (elementary analysis)*.

International Organization for Standardisation 1996, *AS/NZS ISO 14001:1996 Environmental management systems—specification with guidance for use*.

International Organization for Standardisation 1998, ISO 14235:1998, Soil quality -- Determination of organic carbon by sulfochromic oxidation

South Australian Environment Protection Authority 2000, *Consultation draft guidelines for separation distances, viewed 22 December 2006,*<www.epa.sa.gov.au/pdfs/sepguidepcd.pdf>.

South Australian Environment Protection Authority, *DRAFT Guidelines—Groundwater investigation, assessment and monitoring for landfills for municipal solid waste and commercial and industrial general waste, (to be published in 2007)*.

South Australian Environment Protection Authority 2003, *Guidelines for community consultation for waste management and recycling facilities,* viewed 22 December 2006, <www.epa.sa.gov.au/pdfs/guide_consultation.pdf>.

South Australian Environment Protection Authority 1997, *Stormwater pollution prevention code of practice for local, state and federal government*, EPA, Adelaide.

South Australian Environment Protection Authority 1999, *Stormwater pollution prevention code of practice for the building and construction industry*, EPA, Adelaide.

Standards Australia, *AS 1289 Methods of testing soils for engineering purposes*, Standards Australia, New South Wales.

Standards Australia, *AS 1726 Geotechnical site investigations*, Standards Australia, New South Wales.

Standards Australia, *AS 3798-1996 Guidelines on earthworks for commercial and residential developments*, Standards Australia, New South Wales.

### 15.1.1 Legislation and Environment Protection Policies

*Development Act 1993* (SA).

*Environment Protection Act 1993* (SA).

*Environment Protection (Air Quality) Policy 1994* (SA).

*Environment Protection (Water Quality) Policy 2015* (SA).

*Environmental Protection and Biodiversity Conservation Act 1999* (SA).

*Flora and Fauna Guarantee Act* 1988 (Vic).

### 15.1.2 Modelling programs

Environment Agency United Kingdom 2002, *GasSim*

Environment Agency United Kingdom, *LandSim*, viewed 22 December 2006 , <www.landsim.co.uk>.

National greenhouse gas inventory committee 1996, *LandGEM*, viewed 22 December 2006 <www.epa.gov/ttn/catc/products.html > *This model was prepared by the US Environment Protection Authority. Default parameters for use in the LandGEM model have been published for Australian conditions.*

United States Environmental Protection Agency, *Hydrologic Evaluation of Landfill Performance (HELP), viewed at 22 December 2006,* <http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=landfill>.

## 15.2 Waste type glossary and definitions

| | |
|---|---|
| Cell | Fill area within a stage which is operational for six months to one year. |
| Commercial and industrial waste (general) | Commercial and industrial waste (general) means the general component of the solid waste stream arising from commercial, industrial, government, public or domestic premises (not collected as municipal solid waste), but does not contain listed wastes, hazardous wastes or radioactive wastes. |
| Construction and demolition waste (inert) | Construction and demolition waste (inert) means the solid inert component of the waste stream arising from the construction, demolition or refurbishment of buildings or infrastructure.<br><br>Note: The intent of this definition is to aim for inert waste with no contamination by foreign material. However, it is acknowledged that it may be impractical to define that 0% is part of the definition. As such, it is acknowledged that, with the aim of no contamination, there may be some negligible components of foreign material contained in the waste. Therefore, as a maximum, C&D inert must not contain more than 5% by volume per load of foreign material within the accepted meaning of the definition and this must not include any liquid, listed, hazardous or radioactive wastes. |
| Construction and demolition waste (mixed) | Construction and demolition waste (mixed) means the solid component of the construction and demolition waste stream containing foreign material typically arising from the construction, demolition or refurbishment of buildings or infrastructure, but does not contain listed wastes, hazardous wastes or radioactive wastes.<br><br>NOTE: C&D waste is considered 'mixed' if it contains foreign material that would render the load of waste no longer inert. As a maximum, C&D waste with more than 5% by volume per load of foreign material (not being liquid, listed, hazardous or radioactive waste) within the accepted meaning of the definition, would be considered mixed. |
| Hazardous waste | Hazardous waste is any unwanted or discarded material (excluding radioactive material), which because of its physical, chemical or infectious characteristics can cause significant hazard to human health or the environment when improperly treated, stored, transported, disposed of or otherwise managed. |
| Inert waste | Inert waste is solid waste that has no active chemical or biological properties and is not subject to biological or chemical breakdown. These wastes do not undergo environmentally significant physical, chemical or biological transformation and have negligible potential to cause environmental harm. |
| Karstic | Limestone rocks that are highly eroded with channelled outcroppings. |
| Large landfill | Total waste capacity greater than 130 000 tonnes (approximately 200 000 cubic metres). |
| Listed waste | Listed wastes are those wastes listed in Part B of Schedule 1 of the *Environment Protection Act 1993*. |
| Medium landfill | Total waste capacity between 26 000 tonnes (approximately 52 000 cubic metres) and 130 000 tonnes (approximately 200 000 cubic metres). |

| | |
|---|---|
| Municipal solid waste—hard waste | The component of the municipal solid waste stream which is not suitable for collection using a bin system, but does not contain listed wastes, hazardous wastes or radioactive wastes.<br><br>Note: hard waste is typically collected in campaigns by councils who also advise on waste that is suitable for that collection. |
| Municipal solid waste—kerbside bin collection | Municipal solid waste means the solid component of the waste stream arising from domestic, commercial, industrial, government and public premises including waste from council operations, services and facilities and is collected by or on behalf of the council by kerbside collection, but does not contain listed wastes, hazardous wastes or radioactive wastes. |
| New landfill developments | Includes:<br>• new development applications<br>• development applications lodged and assessment process not finalised<br>• development approval being granted, licence applications being lodged or licences already granted<br>• any new development within an existing site. |
| Small landfill | Total waste capacity less than 26 000 tonnes (approximately 52 000 cubic metres). |
| Stage (or zone) | landfill area operational for three to five years; shall include areas of related activities, such as waste treatment, recycling and composting, if applicable. |
| Waste operational area | Comprises all closed, operational and future elements in a landfill facility (Landfill operational elements include wheel wash, leachate ponds, storage and other associated landfill activities.) |

Note: waste definitions are in a constant state of review and development. Please check <www.epa.sa.gov.au> to ensure that all definitions are up-to-date.

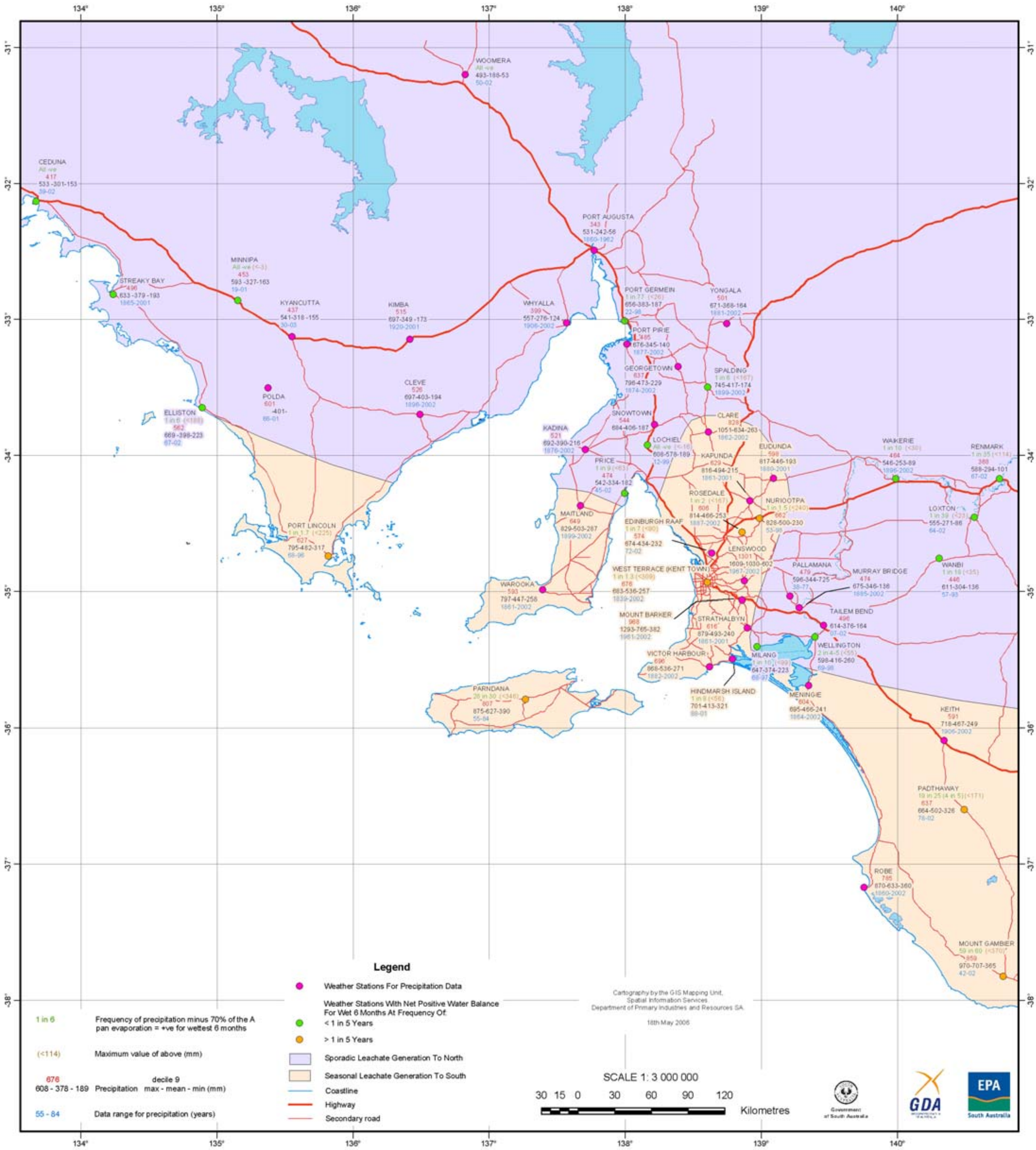
# 16 ATTACHMENTS

## 16.1 Attachment 1—Examples of landfill classification for design of landfill facilities

| Site example | Landfill type based on waste disposal | Landfill type based on site conditions | Landfill classification |
|---|---|---|---|
| Site 1 in the far north | Type S because the site has a total capacity of 15 000 tonnes and it is not practical to participate in a regional waste management plan. | Type B- due to the following:<br>The site has groundwater at a depth of 15 m with a salinity of 6000 mg/L and a low risk of impact on the protected environmental values of waters.<br>The geology beneath the site includes 10 m thickness of clay that has good attenuation and seepage retardation properties.<br>There is a low risk of leachate generation from water flow into the waste due to site conditions and stormwater management measures.<br>There will not be waste of high moisture content disposed at the landfill.<br>The climatic conditions at this site indicate that there is a sporadic potential to generate leachate (refer to Attachment 2). | SB- |
| Site 2 in the Southeast | Type M because the site has a total capacity of 100 000 tonnes. | Type B+ due to the following:<br>The site has groundwater with a salinity of 800 mg/L and has sensitive protected environmental values as potable water and for aquatic ecosystems. There is a high risk of impact on the protected environmental values of waters.<br>The geology beneath the site is limestone and has poor attenuation and seepage retardation properties.<br>The climatic conditions in this part of the Southeast indicate that there is a seasonal potential to generate leachate (refer to Attachment 2). | MB+ |
| Site 3 in the Mid-north | As above. | Type B- due to the following:<br>The site has groundwater at a depth of 20 m with a salinity of 8000 mg/L and a low risk of impact on the protected environmental values of waters.<br>The geology beneath the site includes 10 m thickness of clay that has good attenuation and seepage retardation properties. | MB- |

| Site example | Landfill type based on waste disposal | Landfill type based on site conditions | Landfill classification |
|---|---|---|---|
| | | There is no evidence of groundwater pollution from the existing landfill in the groundwater monitoring bores.<br>There is a low risk of leachate generation from water flow into the waste.<br>There will not be waste of high moisture content disposed at the landfill.<br>The climatic conditions in this part of the Mid-north indicate that there is a sporadic potential to generate leachate. | |
| Site 4 servicing metropolitan Adelaide | Type L because the site has a total capacity of 400 000 tonnes. | N/A | L |

## 16.2 Attachment 2—Potential for leachate generation based on climatic conditions



## 16.3 Attachment 3—Technical guidance for assessment of materials and methodology for construction of clay liners

The hydraulic conductivity of a clay liner depends on the material properties and the method of construction.

### 16.3.1 Material properties

Assessment of material properties typically includes a program of site investigation and laboratory testing by a NATA accredited laboratory. Site investigation typically includes a program of soil sampling, inspection, logging and laboratory testing by a geotechnical professional in accordance with *AS 1726 Geotechnical Site Investigations*. The program typically includes sampling in surface exposures, test pits and/or boreholes. Considerations include the following:

- particle size distribution (*AS 1289 3.6.1*). Typically, the maximum particle size should be about one third the thickness of each layer prior to compaction (for example, a maximum particle size of 66 mm for a 200 mm-thick layer). Typically, there should be more than 90% passing the 19 mm sieve, 70% passing the 2.36 mm sieve and more than 30 % passing the 0.075 mm sieve (fine grained material)
- Atterberg Limits (*AS 1289 3.1.1, 3.2.1, 3.3.1, 3.4.1*). These tests measure soil plasticity and provide an indication of the plasticity, sensitivity to moisture conditioning and the susceptibility to undergo desiccation cracking with reductions in moisture content. Clays with a low plasticity index (liquid limit less than 50%) are generally more sensitive to moisture conditioning and less susceptible to desiccation cracking compared with clays with a high plasticity index (liquid limit greater than 50%). Generally, clay soils for low permeability liner construction would have a plasticity index of greater than 10%. If a higher calcium carbonate content is suggested for the liner material, the durability and long-term performance of the material needs to be assessed and justified in the design on a site-by-site basis
- dispersion (*AS 1289 3.8.1*). Clay soils should have a low susceptibility to undergo dispersion
- calcium carbonate content. Clay soils should have a calcium carbonate content of less than 15%
- permeability (hydraulic conductivity). Samples for laboratory permeability testing in accordance with *AS 1289 6.7.3–1999* must be remoulded in layers to a uniform density and moisture condition. Testing should consider the dry density and moisture condition during sample preparation (refer to Section 16.3.2), the composition of water available on site for moisture conditioning during earthworks and the composition of the leachate and vertical surcharge loads. Standard compaction testing (*AS 1289 5.1.1*) must be performed on the sample prior to permeability testing to assess the relationship between dry density and moisture content. This includes the maximum dry density and the optimum moisture content for standard compactive effort. A separate compaction test must be carried out for each permeability test sample. The permeability test method should consider the particle size distribution of the proposed materials. In some cases, it may not be practical to obtain or prepare representative samples for laboratory testing, and testing on a field trial pad may be preferred.

### 16.3.2 Construction methodology

The hydraulic conductivity (permeability) of clay is typically minimised if the clay is moisture conditioned and compacted at a moisture content that is greater than the optimum moisture content in standard compactive effort (*AS 1289 5.1.1*). The optimum moisture content (OMC) is the moisture condition where the dry density of the soil is maximised for a given compactive effort.

Figure 9 presents a typical relationship between hydraulic conductivity and density for different soil moisture conditions during compaction.

Specification of acceptable envelopes of density ratio and moisture condition during compaction (*AS 1289 5.1.1 or AS 1289 5.7.1*) have been effectively used as performance criteria for quality control during liner construction. Acceptable envelopes shall be assessed by testing as part of the design process (see Section 16.3.1). Typically, construction of low permeability clay liners include the following:

- uniform moisture conditioning to between 0 and +3% of the OMC in Standard compactive effort (*AS1289 5.1.1*)
- uniform compaction in layers of less than 200 mm compacted thickness using a sheepsfoot roller to achieve a dry density ratio of greater than 95% relative to Standard compactive effort (*AS1289 5.1.1*)
- effective bonding between layers.

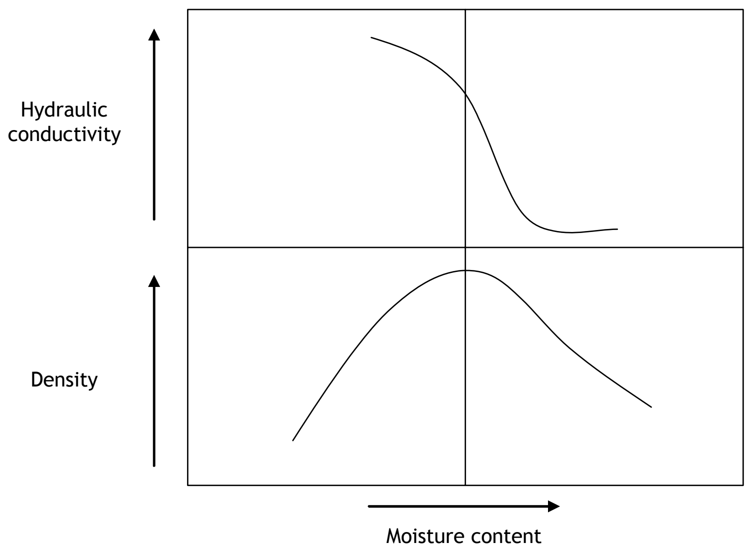



**Figure 9 – Typical relationship between hydraulic conductivity, dry density and moisture content for a clay soil**

## 16.4 Attachment 4—CQA minimum requirements

The quality of geosynthetics used and the quality of the field installation are directly related to the overall performance of the geosynthetics liner system. The works specifications should include detailed construction quality assurance (CQA) requirements to be carried out during the construction of the system.

The CQA plan must be approved by the EPA before commencement of construction works. Any proposed change to the CQA plan must be made in consultation with the EPA.

The installation of the liners must be undertaken by personnel experienced in installation of geosynthetics, and must be carried out in the full-time presence of an experienced and independent CQA officer who must not be in the employ of the geosynthetics supplier or the installation contractor. At the completion of the works, the CQA officer should provide a report on the CQA program and a statement of whether the geosynthetics systems have been installed in accordance with the specifications.

Test information should be provided by the supplier and installation contractors before and during the construction of the liner system to facilitate checking and corrective actions where appropriate. The following testing is considered the minimum information required to be reported for the installed geosynthetics liner system:

- test results of the delivered materials to the site compared with the specified material requirements
- the integrity of the materials delivered to the site and during handling and placement
- test results of non-destructive tests on joins and seams
- test results of destructive tests on joins and seams
- an as-constructed record of the location of repaired defects, joins and seams.

All information shall be presented in a construction report for approval by the EPA.

## 16.5 Attachment 5—Minimum properties for various geosynthetic lining materials for base liner systems

Tables B1 and B2 provide minimum properties for HDPE and GCL geosynthetic lining materials. These minimum properties are intended to provide a guide related to survivability during installation and joining. The design of the liner system may require additional parameters or improved values compared with these tables, to provide the design performance of the liner system.

The materials listed behave differently and hence the tables include different properties for different materials. The selection of material should be based on the performance requirement of the base and side liner. In general, the chemical resistance and durability of liner materials are primary considerations, due to the waste and leachate being in contact with the base geosynthetic materials.

Testing frequencies of the materials should be related to the area being lined for the project and the parameter being tested.

**Table B1 High density polyethylene (HDPE) geomembrane (smooth or textured)**

| Property | Value | Test method ASTM |
|---|---|---|
| Density | ≥ 0.94 g/cm$^3$ | D1505 |
| Elongation at break (smooth liner) | ≥700% | D6693 |
| Elongation at break (textured liner) | ≥100% | |
| Elongation at yield | ≥12% | D6693 |
| Puncture resistance | ≥400 N | D4833 |
| Notched content tensile test resistance | ≥300 hours | D5397 |
| Carbon black content | 2-3% | D1603 |
| Standard oxidative induction time (OIT) | >100 minutes | D3895 |
| Oven aging at 85 °C—standard OIT | >55% | D3895 |

**Table B2 Geosynthetic clay liner (GCL)**

| Property | Value | Test method ASTM |
|---|---|---|
| Mass of top and bottom geotextile | >100 g/m$^2$ | D5261 |
| Mass of sodium bentonite or | >3000 g/m$^2$ | D5993 |
| mass of calcium bentonite | >6000 g/m$^2$ | |
| Bentonite swell index | >16 mL/2g | D5890 |
| Peel strength | >300 N/m | D6496 |

## 16.6 Attachment 6—Minimum properties for various geosynthetic lining materials for caps

Tables C1 to C5 provide minimum properties for various geosynthetic lining materials. These minimum properties are intended to provide a guide related to survivability during installation and joining. The design of the liner system may require additional parameters or improved values compared with these tables, to provide the design performance of the liner system.

The materials listed behave differently and hence the tables include different properties for different materials. The selection of material should be based on the performance requirement of the cap. In general, the more flexible materials listed in the tables would be considered for a cap, to better accommodate deformation of the cap due to waste settlement. Chemical resistance of cap materials is generally a secondary consideration, due to the waste and leachate usually not being in contact with the capping geosynthetic materials.

Test frequencies of the materials should be related to the area being lined for the project and the parameter being tested.

**Table C1 High density polyethylene (HDPE)**

| Property | Value | Test method ASTM |
|---|---|---|
| Density | ≥ 0.94 $g/cm^3$ | D1505 |
| Elongation at break | ≥700% | D6693 |
| Elongation at yield | ≥12% | D6693 |
| Puncture resistance | ≥250 N | D4833 |
| Notched content tensile test resistance | ≥300 hours | D5397 |
| Carbon black content | 2-3% | D1603 |
| Standard oxidative induction time | >100 minutes | D3895 |

**Table C2 Linear low density polyethylene (LLDPE)**

| Property | Value | Test method ASTM |
|---|---|---|
| Density | ≥ 0.939 $g/cm^3$ | D1505 |
| Elongation at break | ≥800% | D638 Type III |
| Puncture resistance | ≥120 N | D4833 |
| Axi-symmetric break strain | ≥30% | D5617 |
| Carbon black content | 2-3% | D1603 |
| Standard oxidative induction time | >100 minutes | D3895 |

**Table C3 Polypropylene (PP)**

| Property | Value | Test method ASTM |
|---|---|---|
| Elongation at break (unreinforced) | ≥700% | D638 Type IV |
| Puncture resistance | ≥120 N | D4833 |
| Carbon black content | 2-3% | D1603 |
| High pressure oxidative induction time (oven aging at 85 °C) | >50% retained after 90 days | D5885 |

**Table C4 Polyvinyl chloride (PVC)**

| Property | Value | Test method ASTM |
|---|---|---|
| Density | ≥ 1.2 g/cm$^3$ | D792 |
| Elongation at break | ≥250% | D638 Type IV |
| Tear strength | ≥35 N | D1004 |
| Dimensional stability | <3% | D1204 |
| Volatile loss | <0.5% | D1203 |

**Table C5 Geosynthetic clay liner (GCL)**

| Property | Value | Test method ASTM |
|---|---|---|
| Mass of top and bottom geotextile | >100 g/m$^2$ | D5261 |
| Mass of bentonite | >2500 g/m$^2$ | D5993 |
| Bentonite swell index | >16 mL/2g | D5890 |
| Peel strength | >150 N/m | D6496 |